Hadron Production in Photon-Photon Processes at the ILC and BSM signatures with small mass differences

ILD Analysis Software Meeting

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Introduction

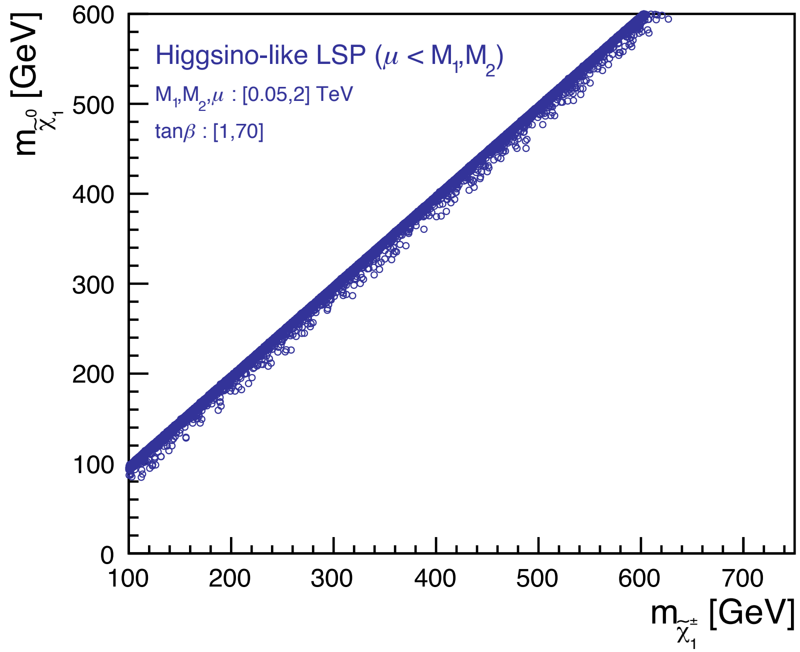
- Naturalness requires light higgsinos at electroweak scale

$$m_Z^2 = 2\frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{\tan^2\beta - 1} - 2\mu^2$$

- Natural region is μ =100-300 GeV - accessible for ILC500 and some at 250 GeV
  [arXiv:1212.2655, arXiv:1404.7510]

- Light higgsinos - $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ nearly mass degenerate

Courtesy: T. Tanabe



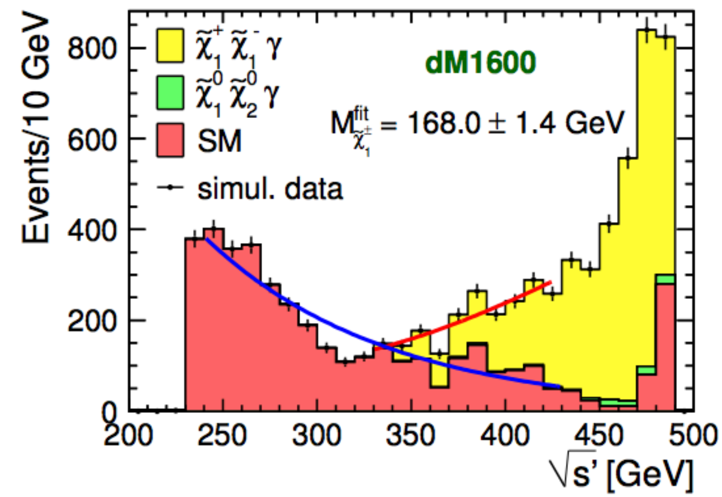
Benchmark Scenario

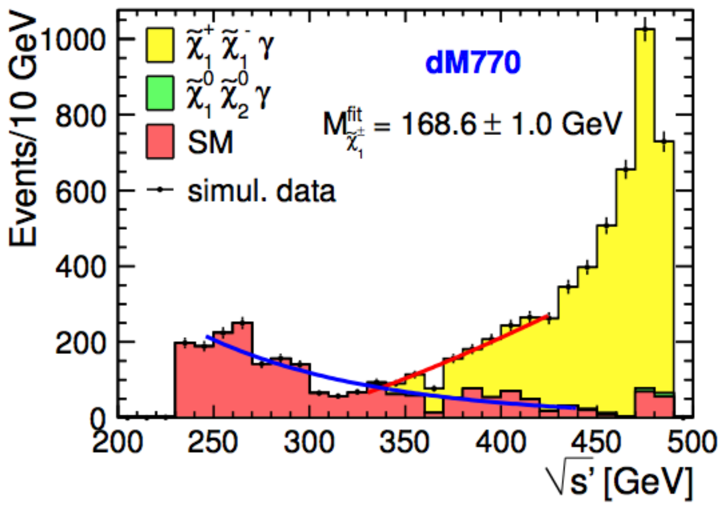
- Light higgsinos $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^{\pm}$ can be discovered/ excluded at ILC - DESY-THESIS-2016-001
- The case was studied at two benchmark scenarios

$$\Delta M(\tilde{X}_1^{\pm}, \tilde{X}_1^0) = 770 \text{ MeV} => \text{dM770}$$

$$\Delta M(\tilde{X}_1^{\pm}, \tilde{X}_1^0) = 1.6 \text{ GeV} => \text{dM1600}$$

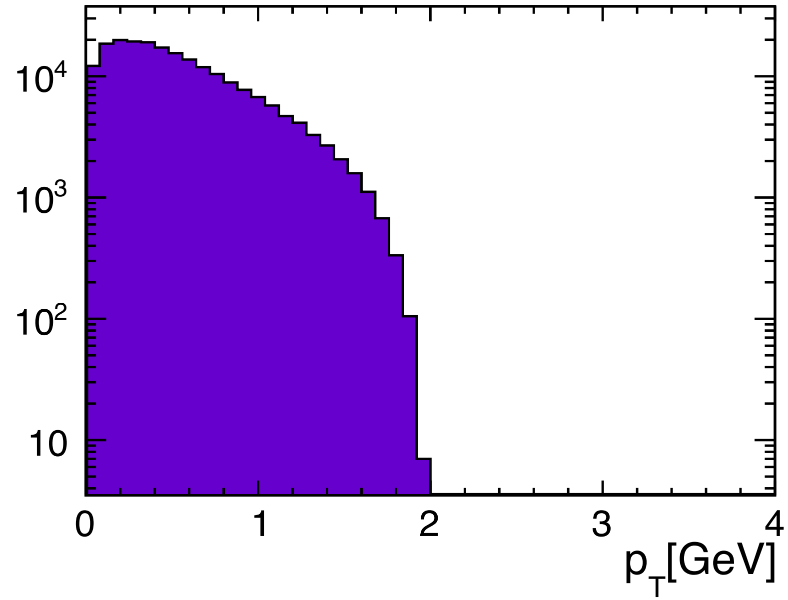
- Charginos decay hadronically and leptonically
- Studied without the inclusion of
  - $\gamma\gamma \rightarrow$ low p_T overlay
  - Pair background





Impact of $\gamma\gamma \to$ low p_T hadron background

- $\gamma\gamma \to$ low pt hadron backgrounds is a challenge for some specific cases e.g low ΔM higgsino
- Visible decay products of higgsinos very soft and thus similar to $\gamma\gamma \to$ low p_T hadron backgrounds
- Analysis for higgsinos still an exception to k_T algorithm method -
  - the low pt visible decay products misidentified as $\gamma\gamma$ overlay in exclusive mode and discarded
- Important to study the effect of overlay on the higgsino events



Possible methods to remove $\gamma\gamma \rightarrow$ low pT hadrons

> Method:

- Displacement of vertices in z direction
- Vertices of $\gamma\gamma$ overlay events displaced from that of signal vertices
- Identifying the tracks coming from such vertices and removing them would be an effective method
- This method cannot be used for purely neutral events like $\gamma\gamma \rightarrow \pi^0\pi^0$

Track grouping algorithm

- Standard vertex finding algorithm reconstructs one single primary vertex for each event

- More complex algorithm to group the tracks to find different vertices

- Grouping based on difference in z0 significance

- New track grouping algorithm which groups the closest tracks separating signal and $\gamma\gamma \rightarrow$ low pt hadron tracks

- Results from dM1600 focused in this talk

Higgino Analysis

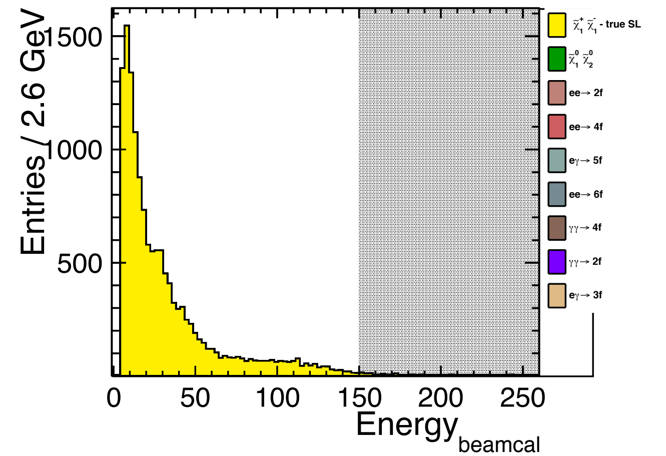
- A full analysis on ΔM higgsinos performed with the inclusion of $\gamma\gamma \rightarrow$ low pT hadron events
- Tracks from signal and overlay are grouped separately using the track grouping algorithm
- A comparison of studies with Hale Serts's analysis is made
- Event selection cuts are adapted from Hale's analysis

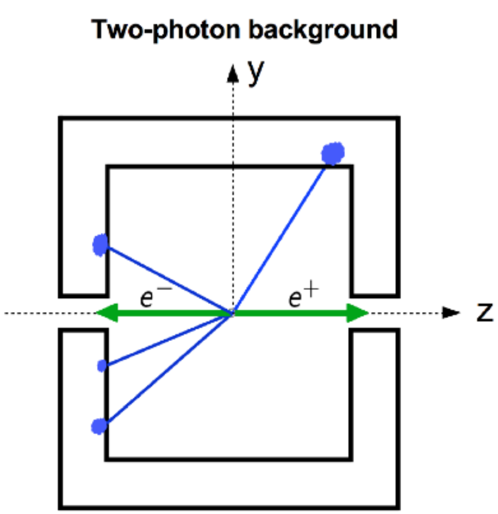
Cuts for Hale Sert's Analysis

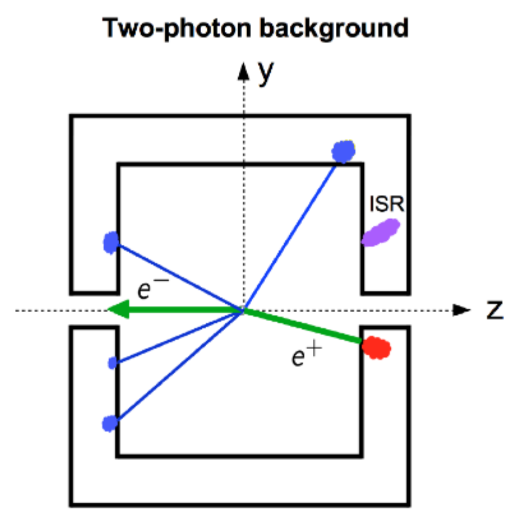
- Events with BeamCal activity vetoed
- Number of tracks < 15
- ISR photon required
- Particles should be 20 degrees away (|Costheta| < 0.9395)
- Energy of every particle in an event < 5
- Missing Energy > 300 GeV
- |Costheta_miss| > 0.993
- Semi-leptonic decay channel
- Boost energy for pions in the chargino rest frame
- Acoplanarity between the decay products

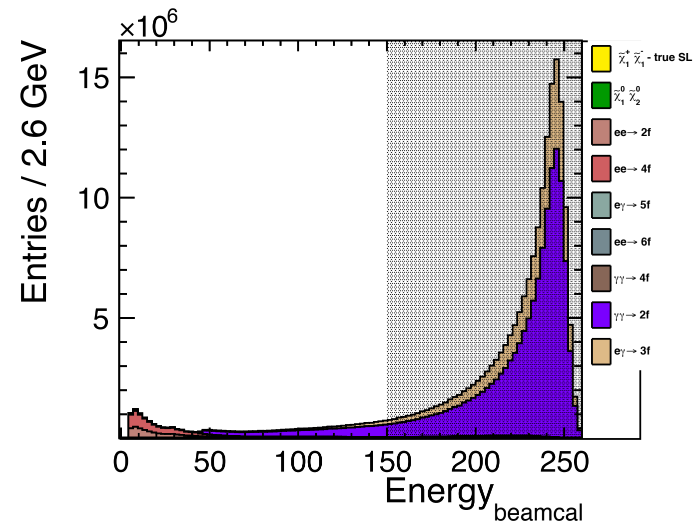
Precuts for the track grouping algorithm

- Events having BeamCal clusters with energy > 150 GeV vetoed
- Number of tracks chosen for the track grouping algorithm < 13
- Every event should have an ISR photon









Semi-leptonic selection for charginos

Truth - level

pi/lep	1 trk grp	2 trk grp	3 trk grp	More trk grp
1 trk grp	8.5	1.3	0.44	0.4
2 trk grp	1.6	0.6	0.35	0.24
3 trk grp	0.6	0.2	0.13	0.20
more trk grp	0.35	0.37	0.11	0.17

Both tracks in one group - 84% 2trk =61%, 3trk= 15%, 4trk = 5%, more = 3.2%

Reco - level

- Total events
- two tracks - 5893 - 64%
- three tracks - 1594 - 17%
- four track - 721 - 8%
- one track - 958 - 11%

$\tilde{\chi}_1^+$ decay mode	BR(dM1600)
$e\nu\tilde{\chi}_1^0$	17.3%
$\mu\nu\tilde{\chi}_1^0$	16.6%
$\pi^+\tilde{\chi}_1^0$	16.5%
$\pi^+\pi^0\tilde{\chi}_1^0$	28.5%

Semi-lep selection for tau events

Truth - level

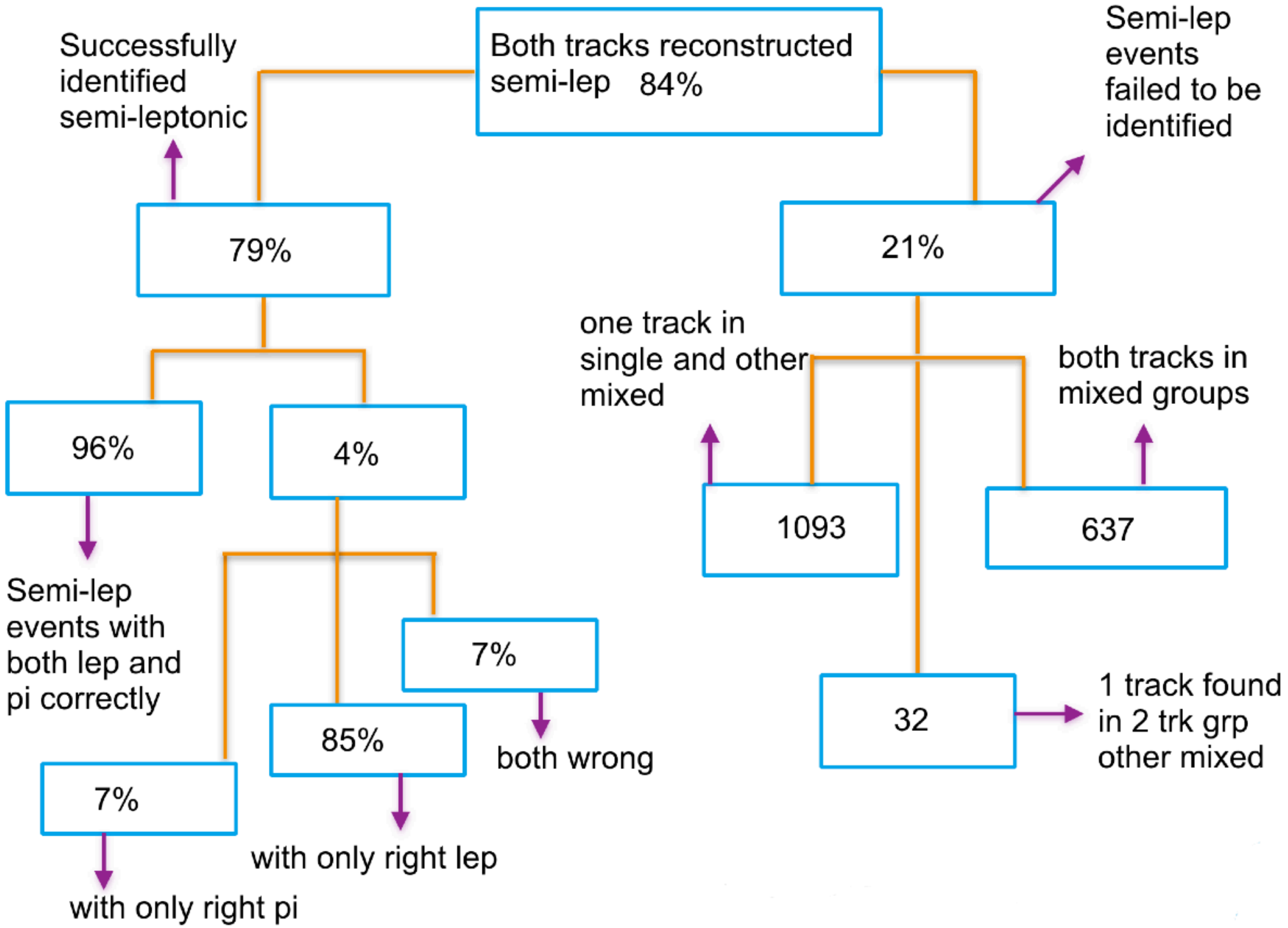
pi/lep	1 trk grp	2 trk grp	3 trk grp	More trk grp
1 trk grp	42	4	3.1	0.7
2 trk grp	4.1	2.3	0.6	0.7
3 trk grp	2.4	0.16	0.12	0.2
more trk grp	0.5	0.30	0	0.17

Reco - level

- Total events
- two tracks - 5.87489e6 - 23 %
- three tracks - 5.08775e6- 20%
- four track - 1.1768e7 - 45%
- One track - 3.11243e6 - 12%

Both tracks in one group - 38.3, 2trk - 29, 3trk = 5.2, 4trk = 3, more = 1.2

Semi-lep selection efficiency



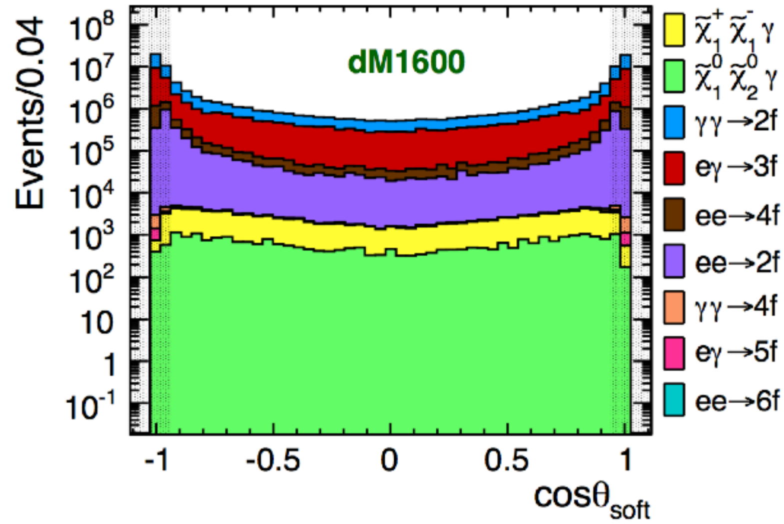
Semi-leptonic selection

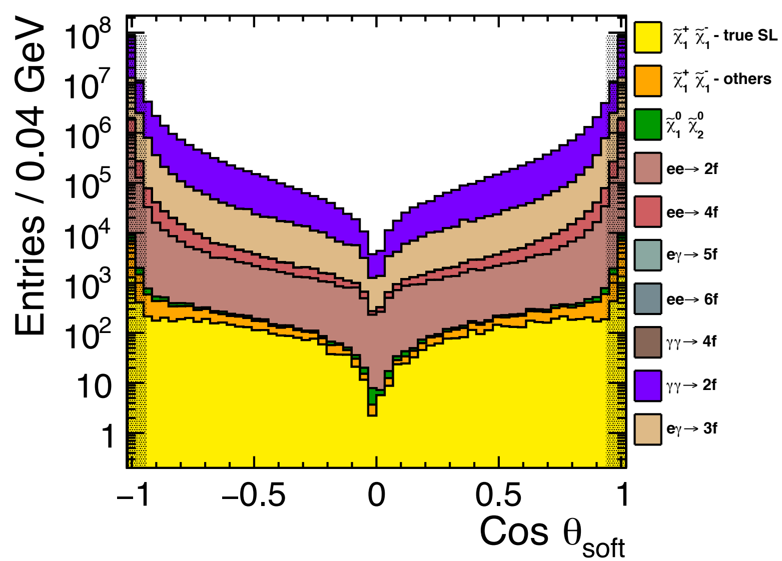
- Without the inclusion of $\gamma\gamma \rightarrow$ low pT hadron overlay, no fake semi-leptonic events are found
- With $\gamma\gamma \rightarrow$ low pT hadron overlay, leptons from di-leptonic events along with pions from overlay imitate semi-leptonic signatures
- With semi-leptonic selection Hale vetoed 96% of SM background
- Presence of fake semi-leptonic signatures makes the cut less effective - 59 % SM background vetoed in Swathi's analysis
- Important to have other cuts that suppress SM background more efficiently

Cos theta$_{soft}$ for the particles

- |Costheta| < 0.9395 for all particles
- $\gamma\gamma \rightarrow$ low pT hadron overlay - majority events with particles having small angle
- Variation in the original cut:
  - Semi-lep events -|Costheta| < 0.9395 only for semi-lep candidates
  - Rest events |Costheta| < 0.9395 for all

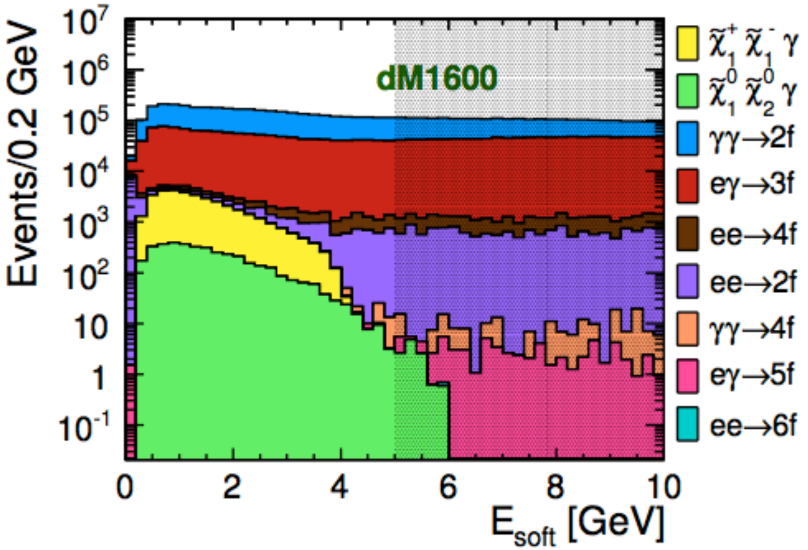
	Sig [%]	SM [%]
Swathi	37	90
Hale	28	72

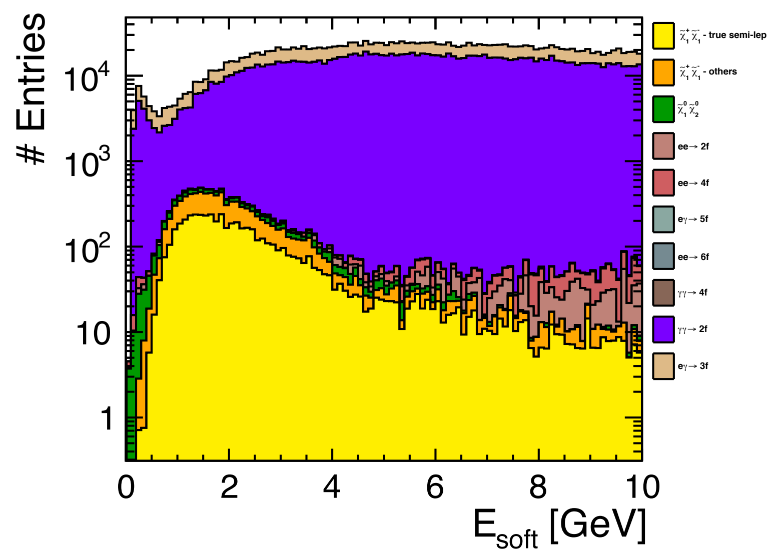




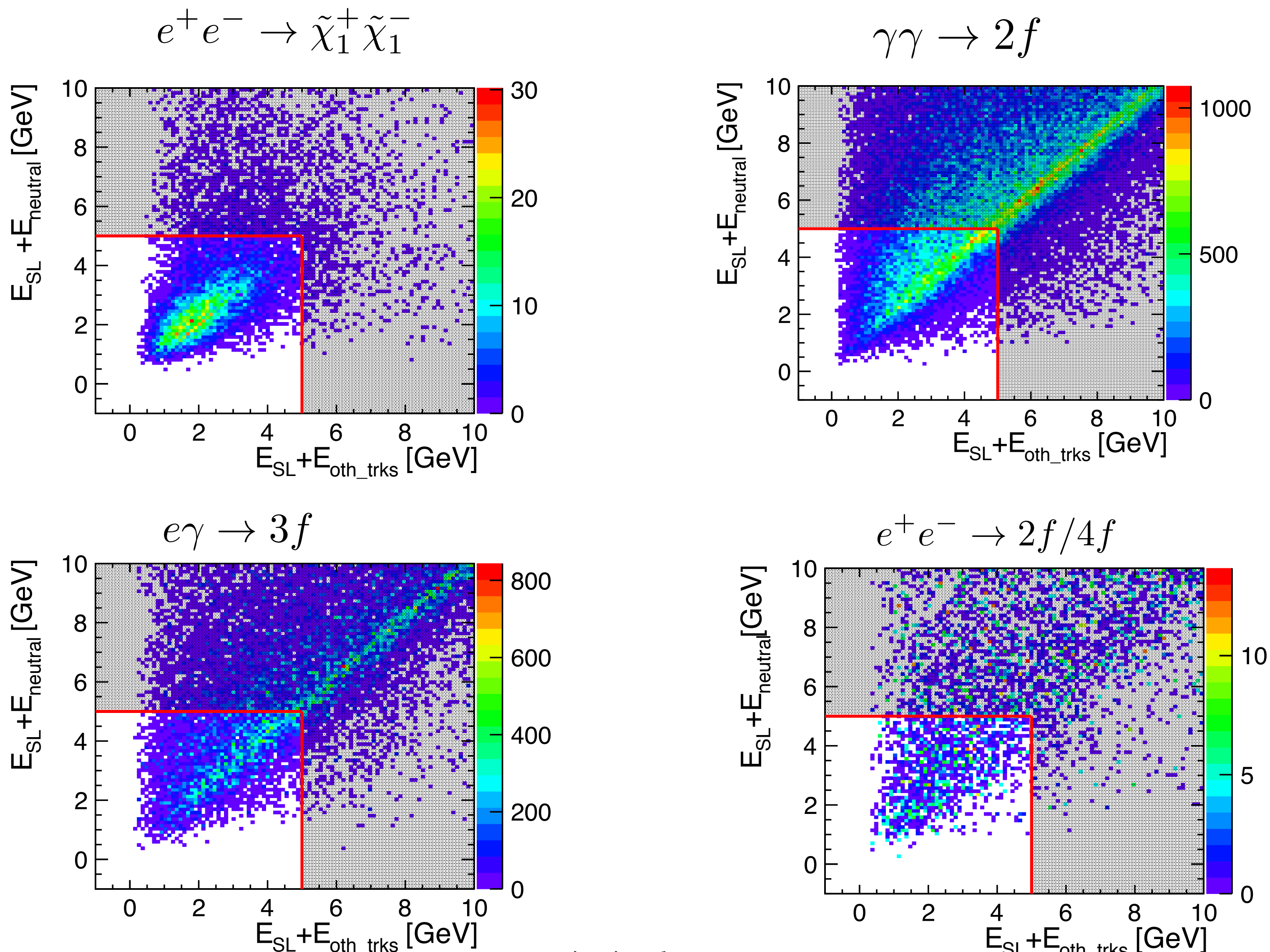
Energy of the particles

- Energy of all particles in event < 5 GeV
- $\gamma\gamma \rightarrow$ low pT hadron overlay, many events with particles with energy > 5 GeV
- Important to have a cut removes majority of background
- Alterations in original cut :
  - $Energy_{SL}$+$Energy_{other\_tracks}$ < 5 GeV
  - $Energy_{SL}$+$Energy_{neutral}$ < 5 GeV





Energy cuts

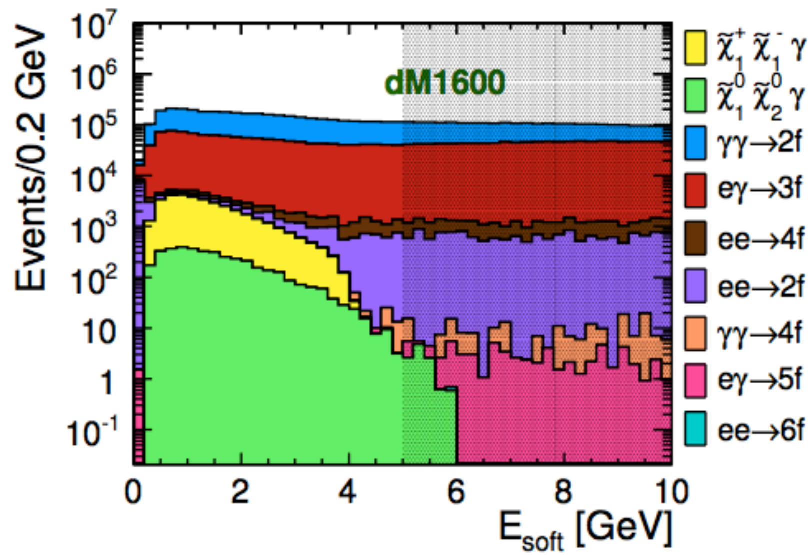


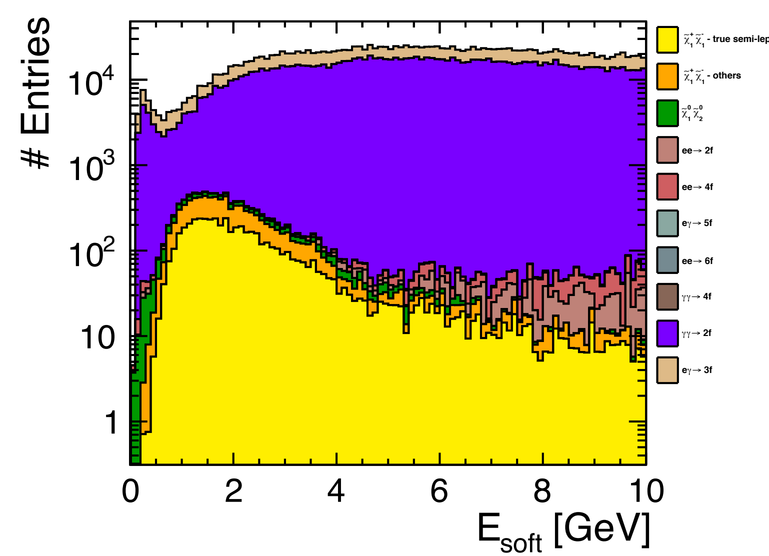
...tion in photon-

Energy of the particles

- Energy of all particles in event < 5 GeV
- $\gamma\gamma \rightarrow$ low pT hadron overlay, many events with particles with energy > 5 GeV
- Important to have a cut removes majority of background
- Alterations in original cut :
  - $\text{Energy}_{\text{SL}}+\text{Energy}_{\text{other\_tracks}} < 5$ GeV
  - $\text{Energy}_{\text{SL}}+\text{Energy}_{\text{neutral}} < 5$ GeV

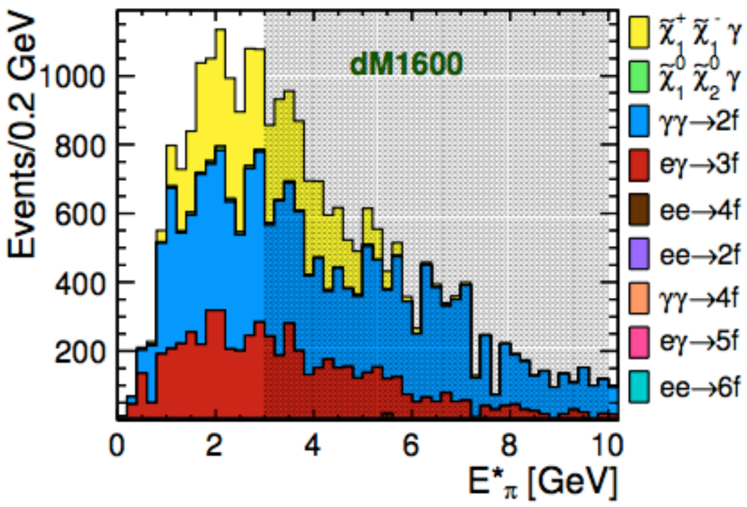
	Sig [%]	SM [%]
Swathi	29	97
Hale	4	81





Boost energy of pion

- Boost energy of pions in chargino pair frame < 3 GeV
- Chargino decay for dM1600 - $\pi^{\pm}$ and π^{0} with BR - 28 %
- Event selection based on charged tracks
- Important to have methods to find right photons decayed from π^{0}



$\tilde{\chi}_1^+$ decay mode	BR(dM1600)
$e\nu\tilde{\chi}_1^0$	17.3%
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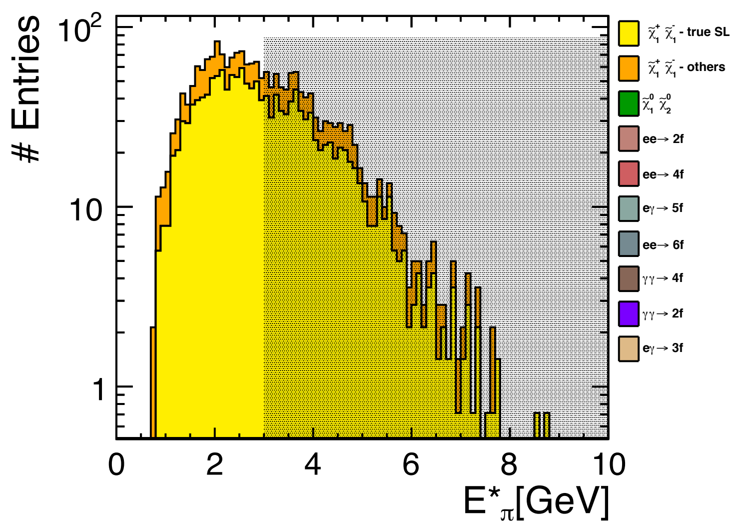
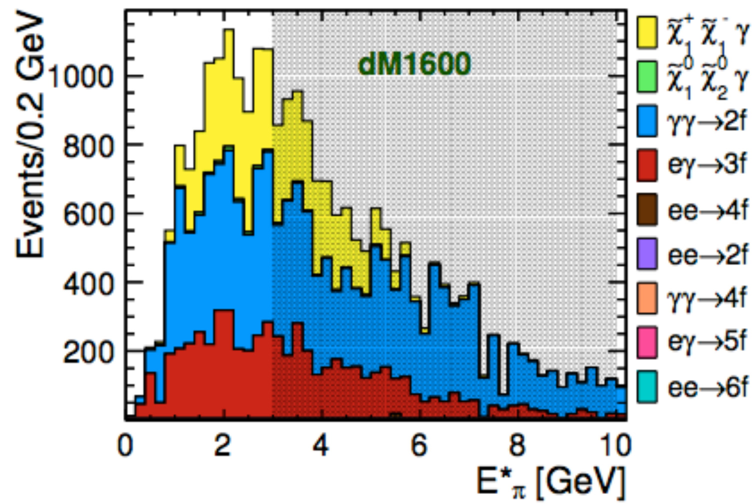


Boost energy of pion

- Boost energy of pions in chargino pair frame < 3 GeV
- Chargino decay for dM1600 - $\pi^{\pm}$ and π^{0} with BR - 28 %
- Boost energy of channel where chargino decays to $\pi^{\pm}$ considered
- 0.3 GeV < Boost Energy < 3 GeV



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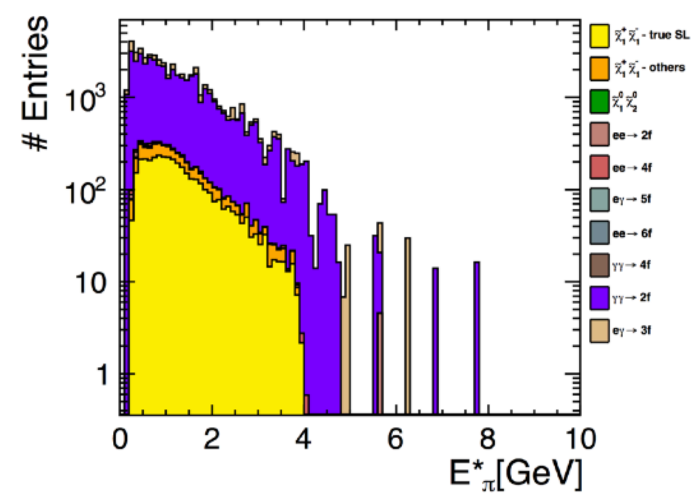


Cut-Flow table

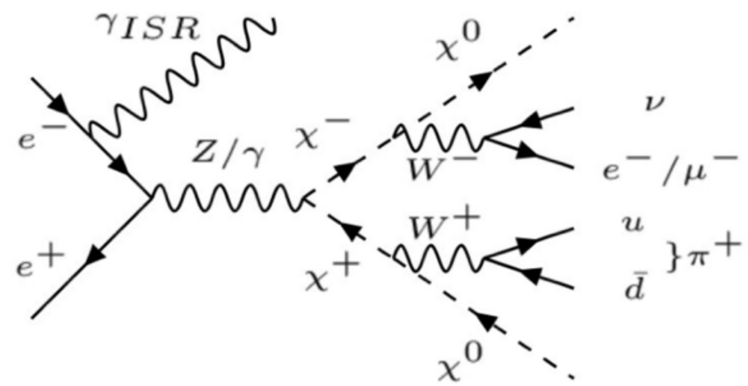
Process	precut	$Costh_{soft}$	ESoft	EMiss	$Costh_{miss}$	semilep
Chargino	9816	6176	4366	4366	4059	3746
ch2	17934	4396	3627	3625	3382	1260
Neutralino	8479	1452	1439	1264	1184	70
ee_2f	2.43E+06	200458	843	166	124	75
ee_4f	2.15E+06	237956	839	347	303	124
aa_2f	1.74E+08	1.795E+07	440555	158335	89589	40883
ae_3f	2.95E+07	3.117E+06	191949	39739	22399	5908

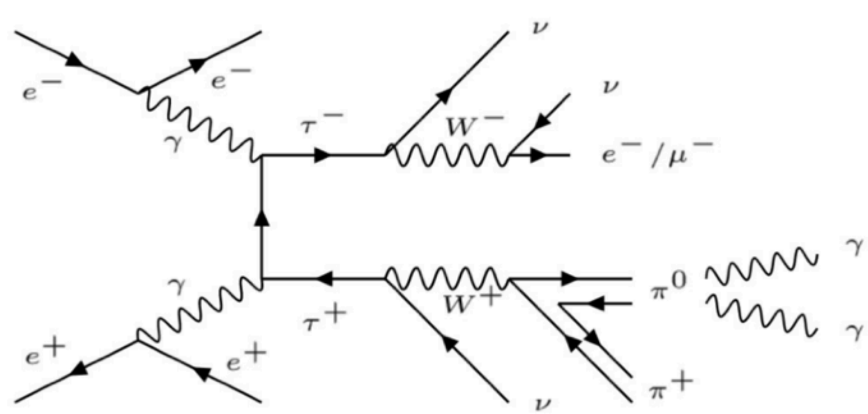
Cut-Flow table

Process	Boost E	acoplanarity	Hale’s Numbers
Chargino	3540	3020	3813
ch2	1176	1009	-
Neutralino	67	64	97
ee_2f	61	52	0
ee_4f	110	97	0
aa_2f	33856	9131	1452
ae_3f	4601	4443	2564

Extra Cuts - strict ISR photon

- Criteria for ISR photon with
  - energy > 10 GeV,
  - |cos theta| > 0.993
- Photons in tau decay can be selected as ISR photon if they fulfill the requirements
- To veto such events :
  - Angle between ISR candidate and nearest track should be larger
  - Invariant mass of the ISR candidate and nearest track $< M_\tau <$ 1.7 GeV





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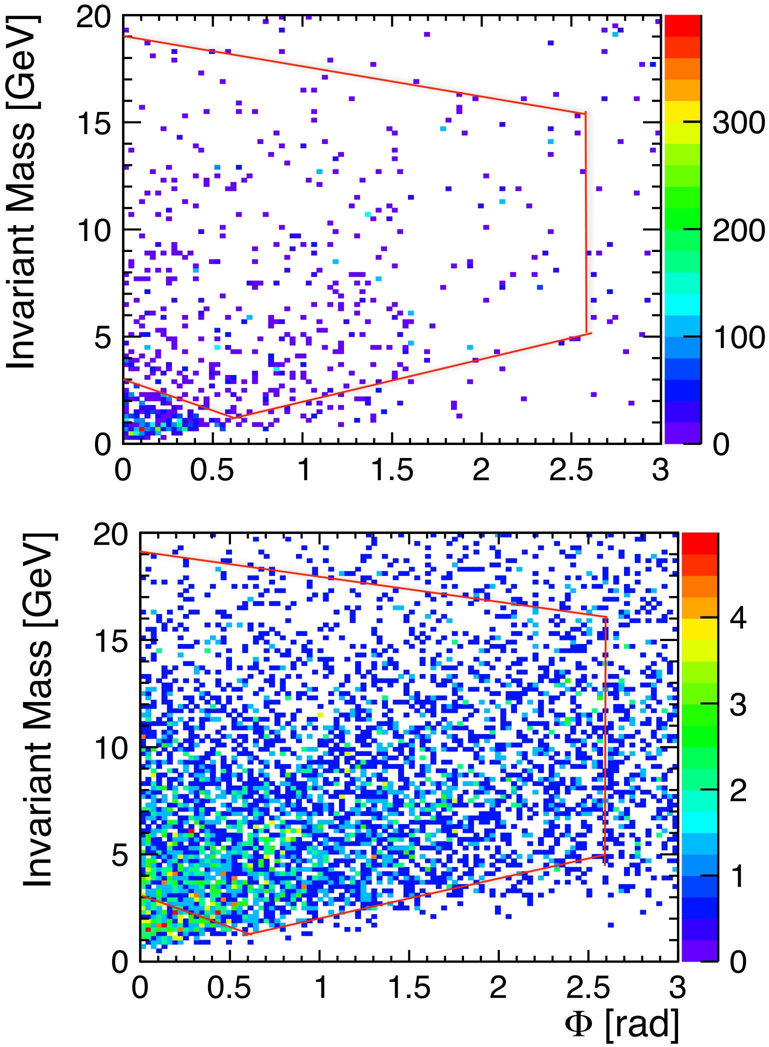
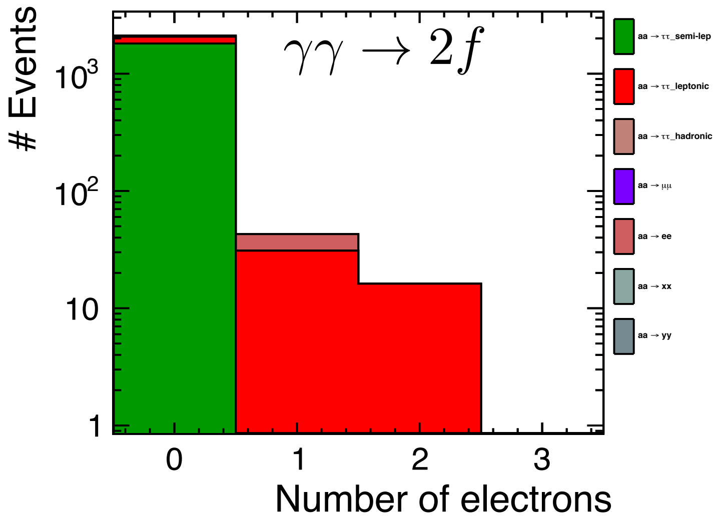


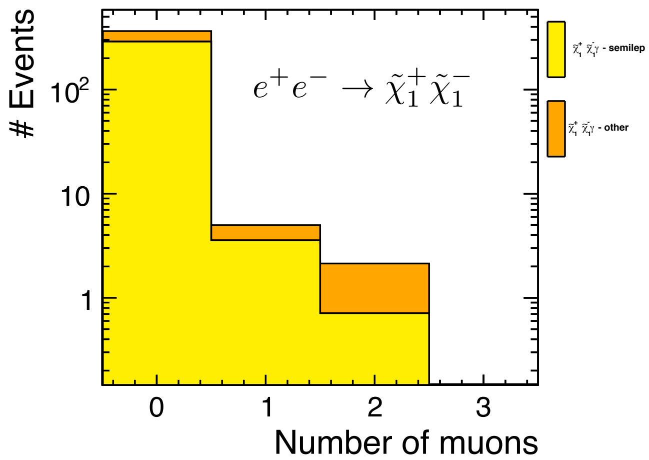
Number of leptons

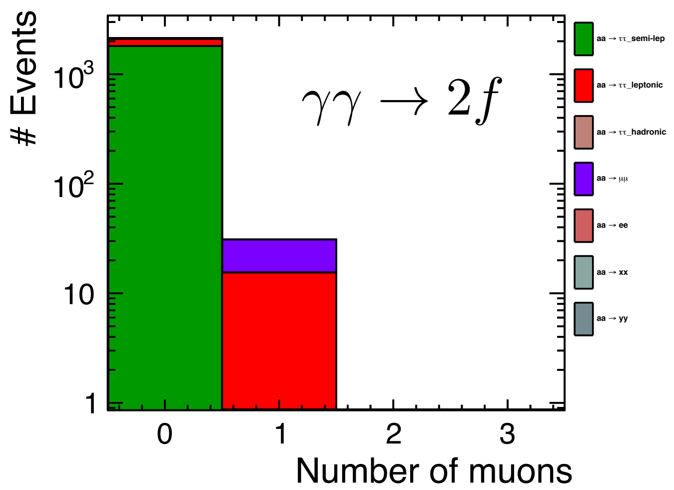
- Semi-leptonic selection of events - lepton from di-leptonic decay channel events along with pions from $\gamma\gamma \rightarrow$ low pT hadron events mimic signatures for semi-leptonic events

- To veto such events - Presence of extra lepton which is oppositely charged to the selected lepton candidate

- If such leptons found then events are vetoed





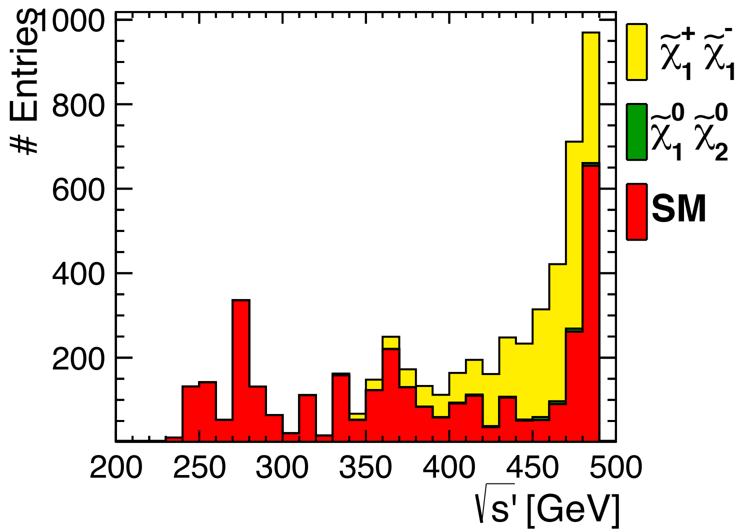


Final Cutflow table

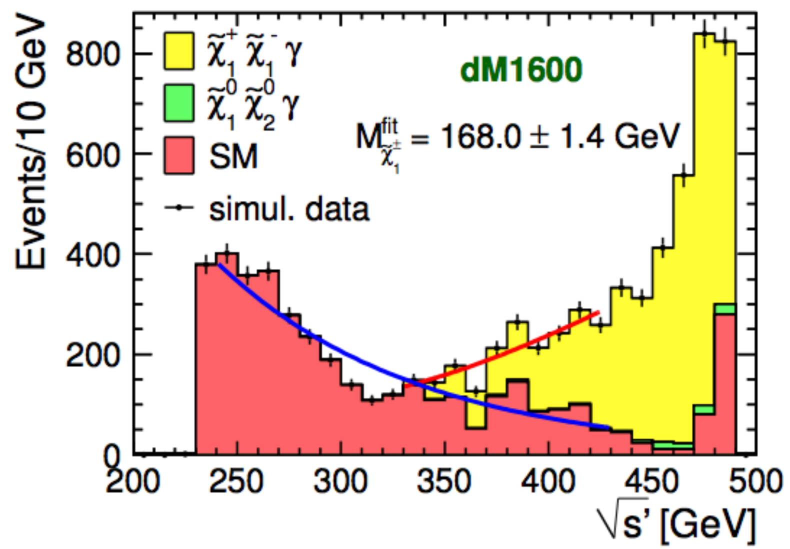
Process	acoplanarity	Strict ISR	Leptons	Hale's numbers	Corrected luminosit
Chargino	3020	2242	2147	3813	2147
ch2	1009	763	704	-	704
Neutralino	64	50	42	97	42
ee_2f	52	37	33	0	33
ee_4f	97	56	29	0	29
aa_2f	9131	3150	2924	1452	1711
ae_3f	4443	2838	2652	2564	1517

Reduced Centr-of-mass Energy

Swathi



Hale

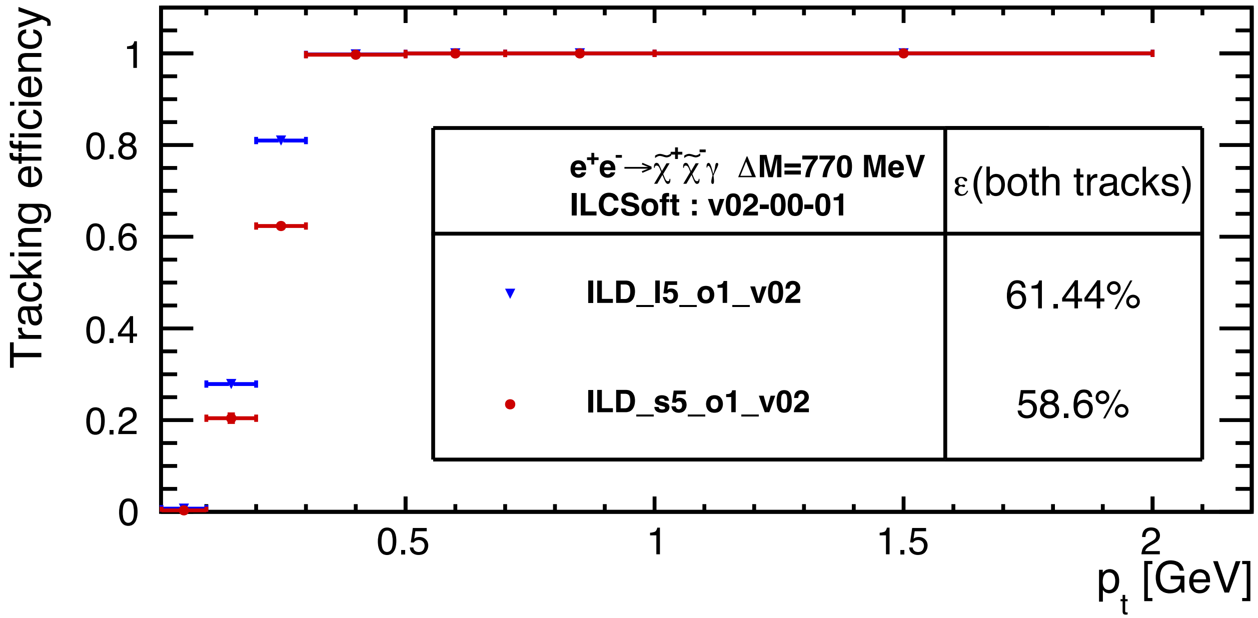


- $\frac{S}{\sqrt{S+B}}$ = 27 for Swathi and 42 for Hale Sert
- Uncertainties on mass and cross-sections to be determined
- Promising result

Conclusion

- The inclusion of $\gamma\gamma \rightarrow$ low pT hadron overlay has a major impact on the dynamics of low ΔM higgsino events
- Comparison between studies with and without the $\gamma\gamma \rightarrow$ low pT radon overlay performed
- Track grouping algorithm to separate signal and overlay tracks developed
- Semi-leptonic selection for events where both the tracks are reconstructed performed efficiently
- Number of background events reduced to similar levels of study without $\gamma\gamma \rightarrow$ low pT hadron overlay
- Signal reduced to 56% of events without the inclusion of $\gamma\gamma \rightarrow$ low pT hadron overlay

Tracking Efficiency

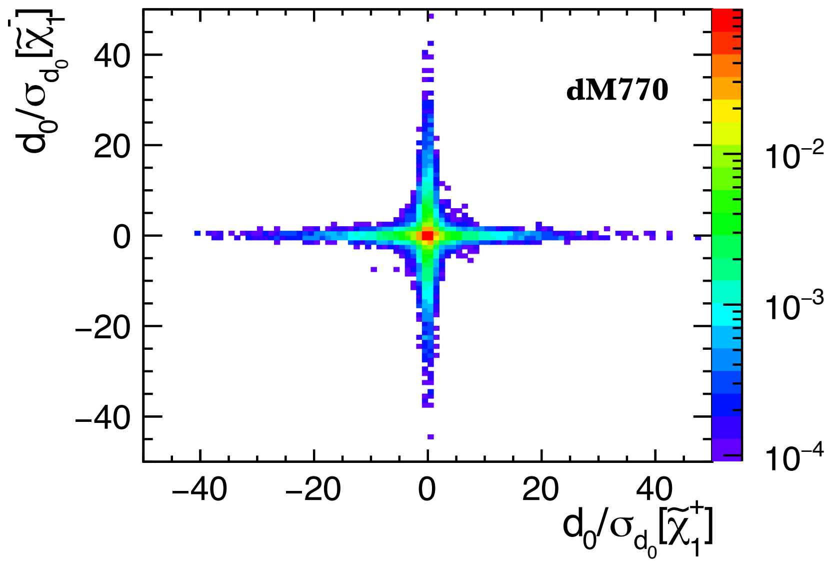


- 100 % tracking efficiency above 300 MeV
- 72 % of total tracks have p_T above 300MeV
- Only events with both tracks reconstructed considered

$\tilde{\chi}_1^+$ decay mode	BR(dM770)
$e\nu\tilde{\chi}_1^0$	15.0%
$\mu\nu\tilde{\chi}_1^0$	13.7%
$\pi^+\tilde{\chi}_1^0$	60.4%
$\pi^+\pi^0\tilde{\chi}_1^0$	7.3%
$\pi^+\pi^0\pi^0\tilde{\chi}_1^0$	0.03%

Removal of high d_0 tracks

- For dM770 tracks with higher d_0 mostly include signal tracks
- Among the tracks coming from two charginos - one has higher d_0 other lower
- For dM770 track with highest d_0 treated separately assuming to be one signal track

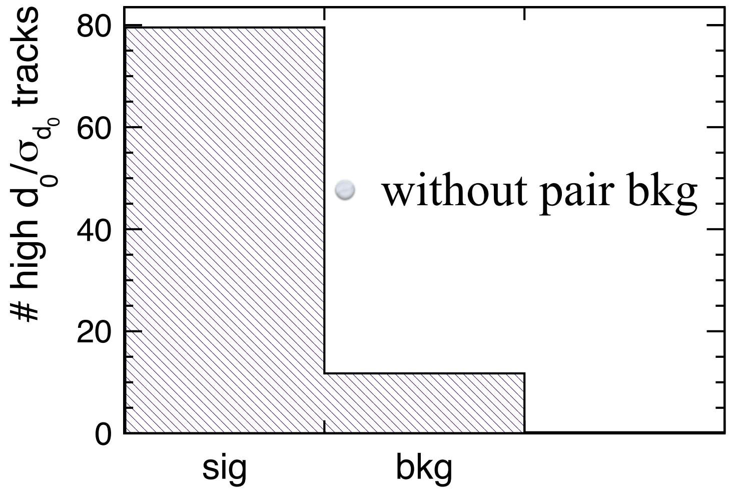


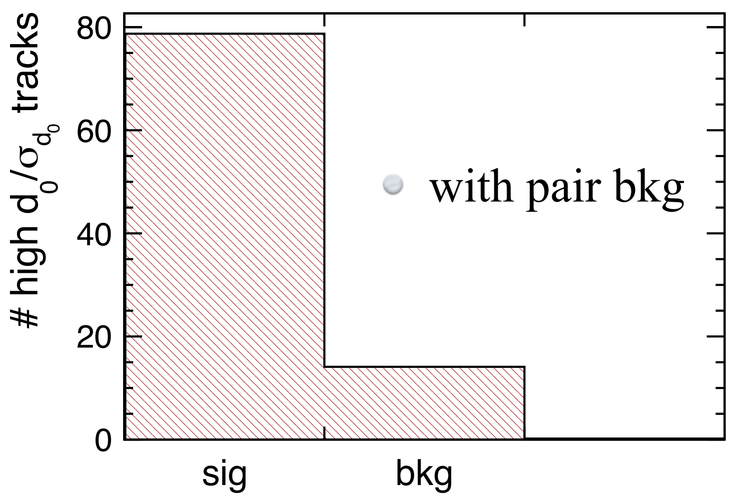
dM1600

$\tilde{\chi}_1^+$ decay mode	BR(dM770)
$e\nu\tilde{\chi}_1^0$	15.0%
$\mu\nu\tilde{\chi}_1^0$	13.7%
$\pi^+\tilde{\chi}_1^0$	60.4%
$\pi^+\pi^0\tilde{\chi}_1^0$	7.3%
$\pi^+\pi^0\pi^0\tilde{\chi}_1^0$	0.03%

Separated highest d_0 track

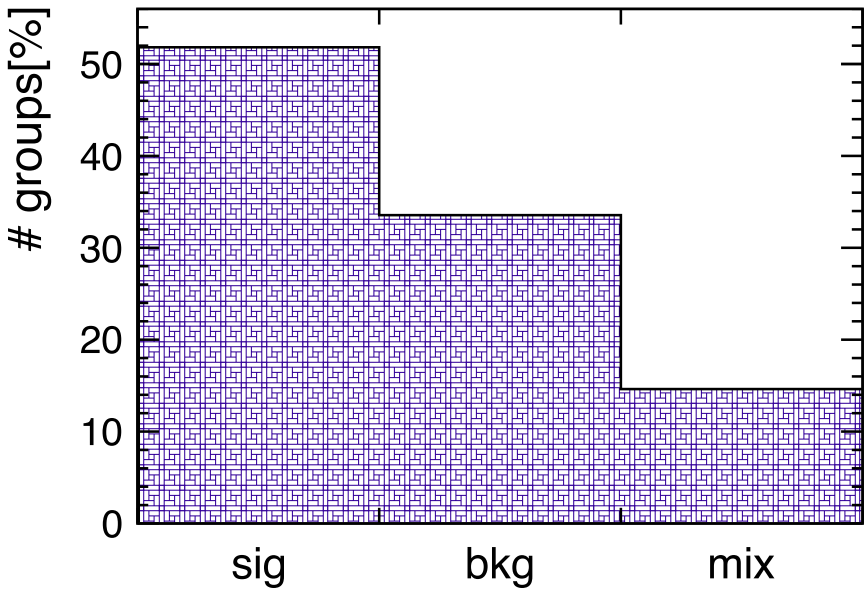
- The track with highest d0 significance value in dM770
- An algorithm to group tracks was developed and the results were shown in Benchmarking days in Arlington
- The whole algorithm transported to processor named “TrackZVertexing”
- The results from the new processor compared with the old results and the new plots are shown



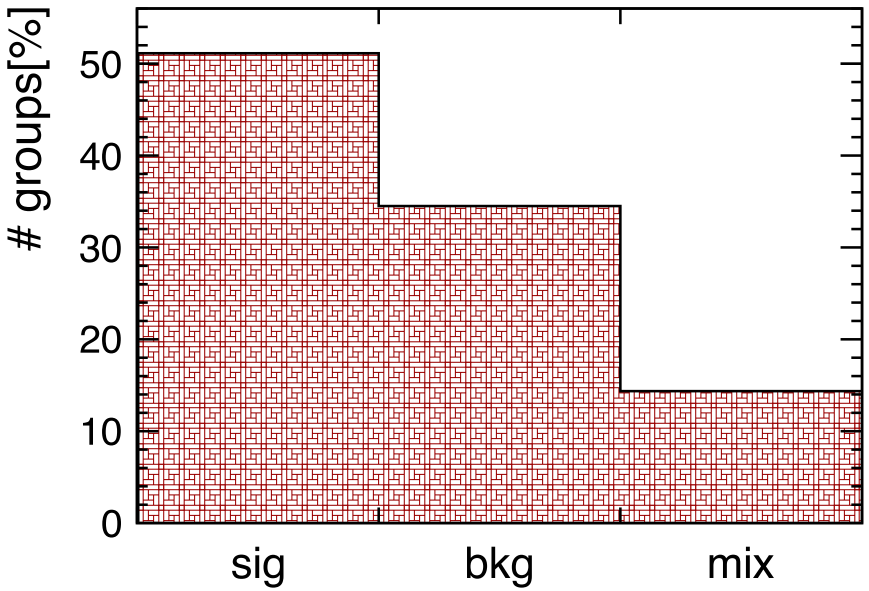


Algorithm Performance (without pair bkg)

- ILD_l5_o1_v02



- ILD_s5_o1_v02

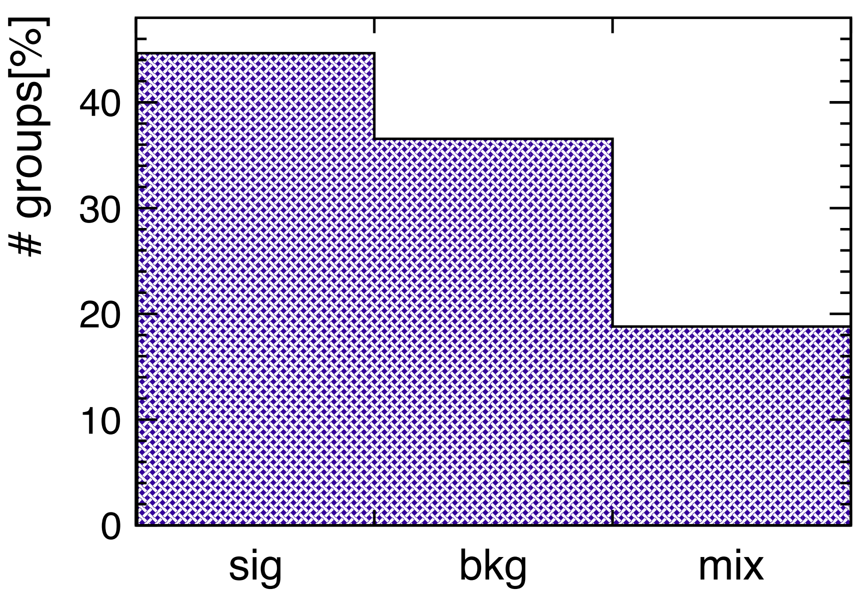


> Signal and background nicely separated

> No. of groups having signal and background mix is meagre

Algorithm Performance (with pair bkg)

- ILD_l5_o1_v02



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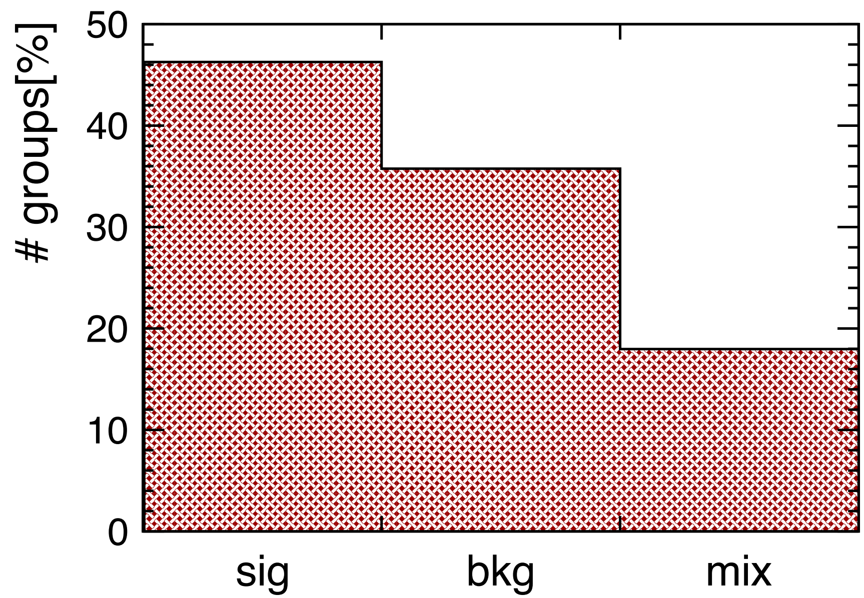
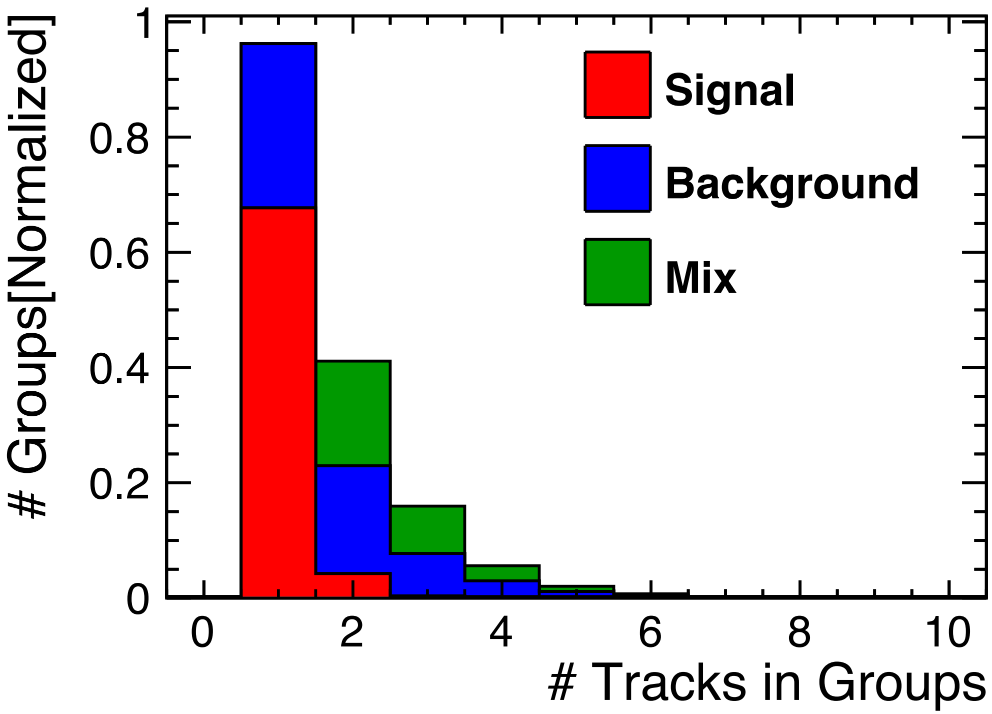


> Grouping done without the exclusion of pair background

> Inclusion of pair background doesn't degrade purity of group much

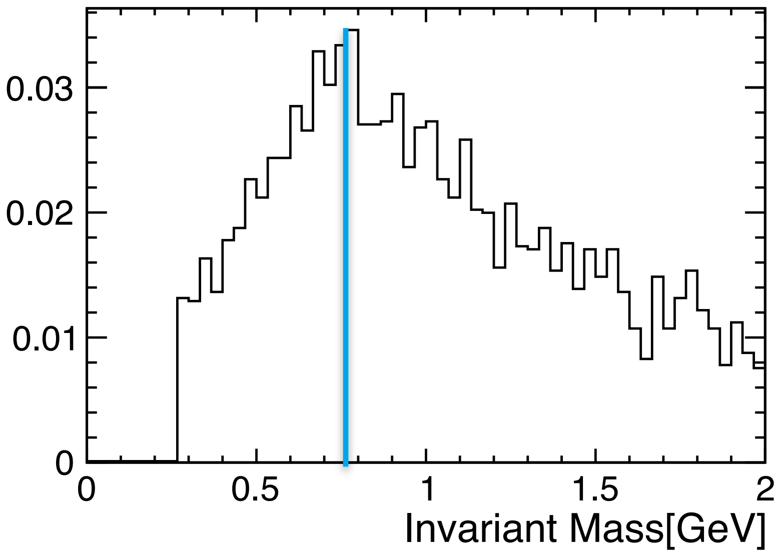
Number of Tracks in Group



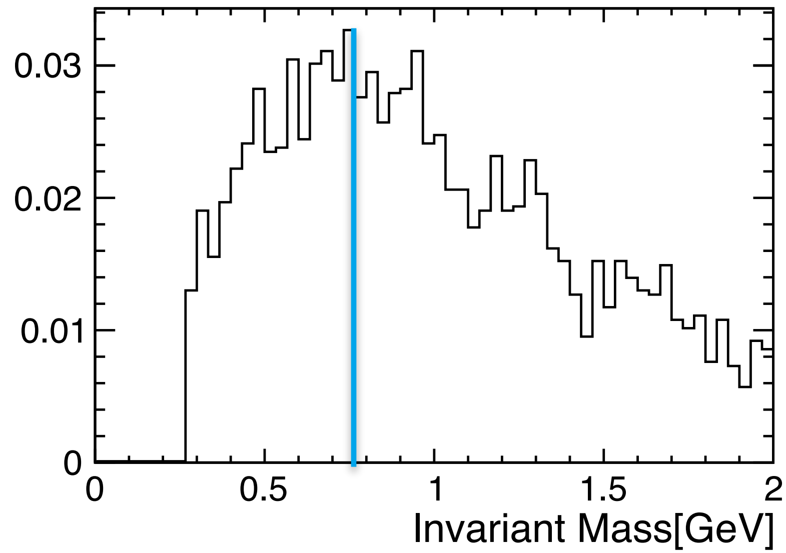
- The number of tracks for signal, bkg and mix groups plotted
- Highest number groups have one track in which majority are signal groups
- Groups with two tracks important to identify backgrounds

Reconstructing invariant mass of rho meson

- ILD_l5_o1_v02



- ILD_s5_o1_v02

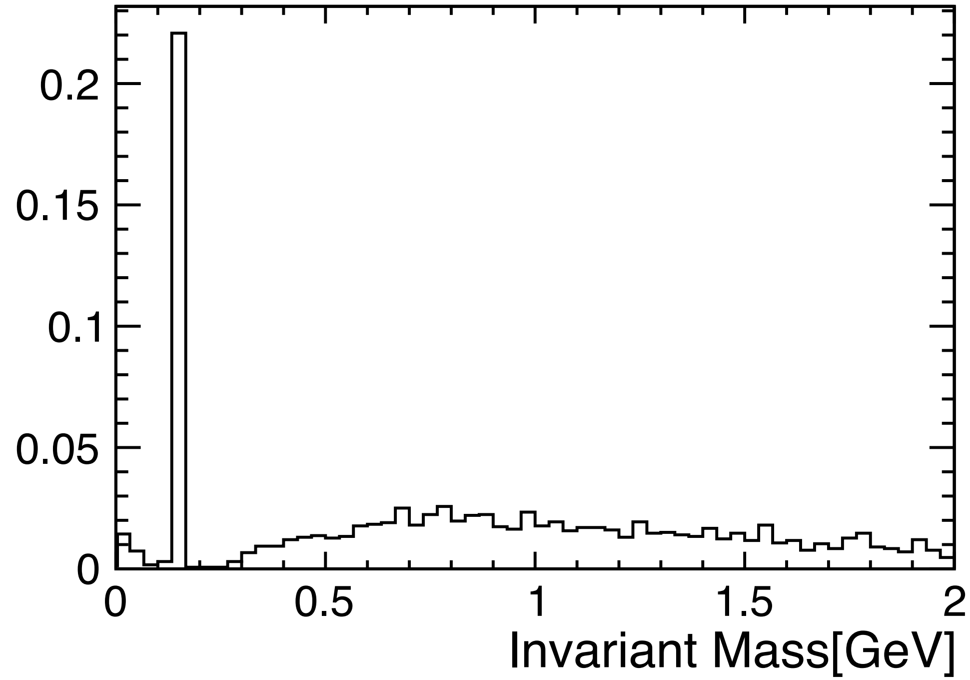


> Invariant mass of a +ve and -ve tracks in a pure background group is calculated and plotted

> For both large and small detector a peak at rho mass (770 MeV) visible

Issues found in Reconstruction

- Invariant mass of rho meson reconstructed using PFO information
- A sharp peak at pion mass is visible
- The PFO's for the given track are not found
- Out of the two tracks in a group, PFO for only one track is found whose mass peaks at pion mass
- Rarely both the PFO's are not found



Conclusion and Outlook

- Impact of $\gamma\gamma \rightarrow$ low pt hadron overlay on the higgsino events very important
- Displaced vertices for the signal and background events and the finite life time of the charginos very important factors to develop new method
- New algorithm leading towards the method to remove the $\gamma\gamma \rightarrow$ low pt hadron events transported to a new processor and is ready to use
- Results very encouraging!!
- Identification of background groups by reconstructing invariant mass from two tracks in a group performed
- Application on full analysis - ongoing
- Final Result Required : Mass reconstruction of chargino after removal of $\gamma\gamma \rightarrow$ low pt background

Questions??

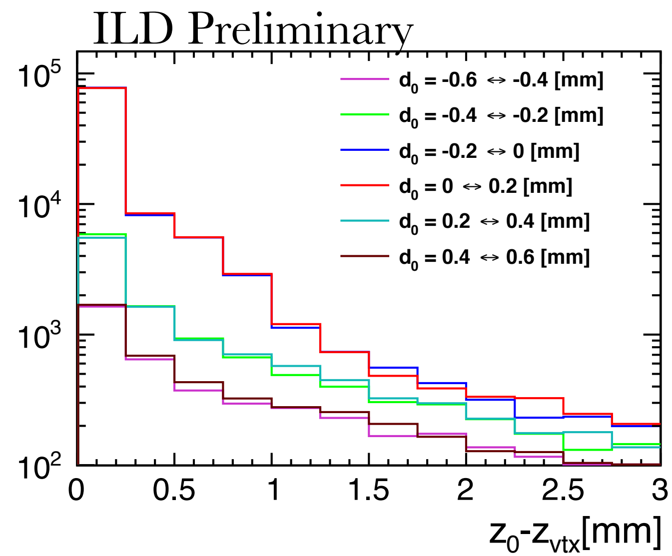
Average position and error

- Weighted avg position = $\Sigma_i \frac{Z_0[track_i]}{Z_0[\sigma_i]} / \Sigma_i \frac{1}{Z_{0[\sigma_i]}}$

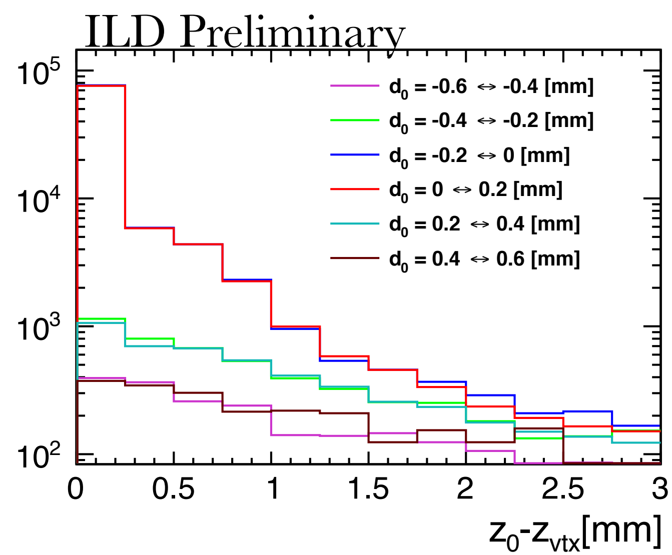
- Weighted Avg Error = $1/\Sigma_i \sqrt{\frac{1}{Z_0[\sigma_i]}}$

d_0 projection on z_0-z_{vtx}

- Group tracks with z_0
- For z_0 to be comparable with z_{vtx} track required to be closest to z-axis
- Tracks with higher d_0 are away from z-axis
- Tracks above certain d_0 threshold value to be treated differently



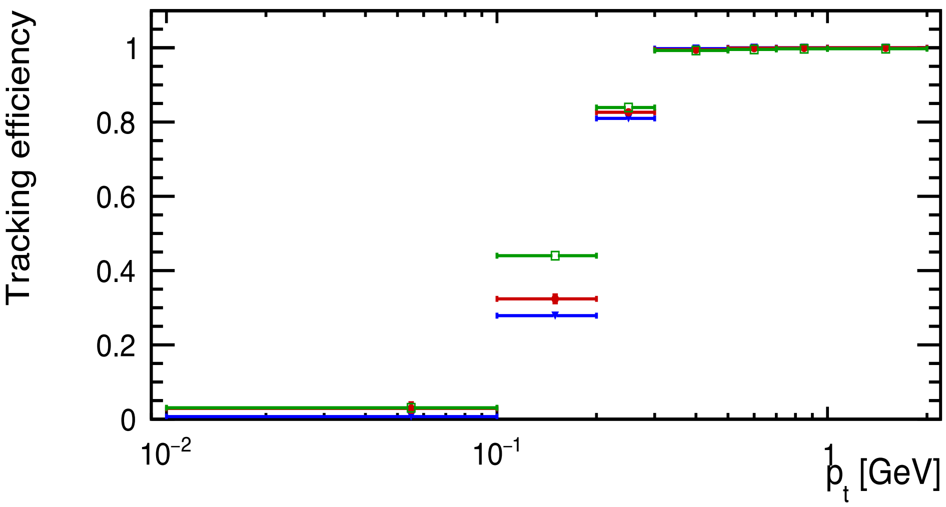
dM770

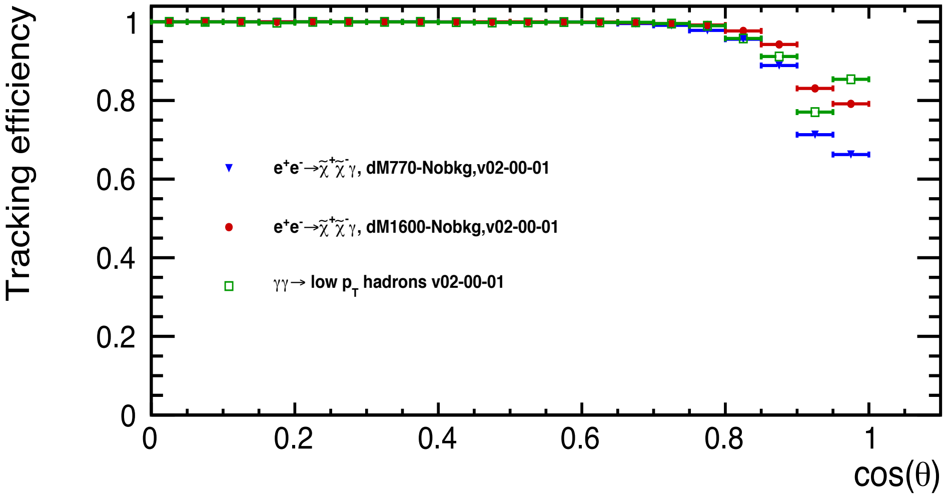


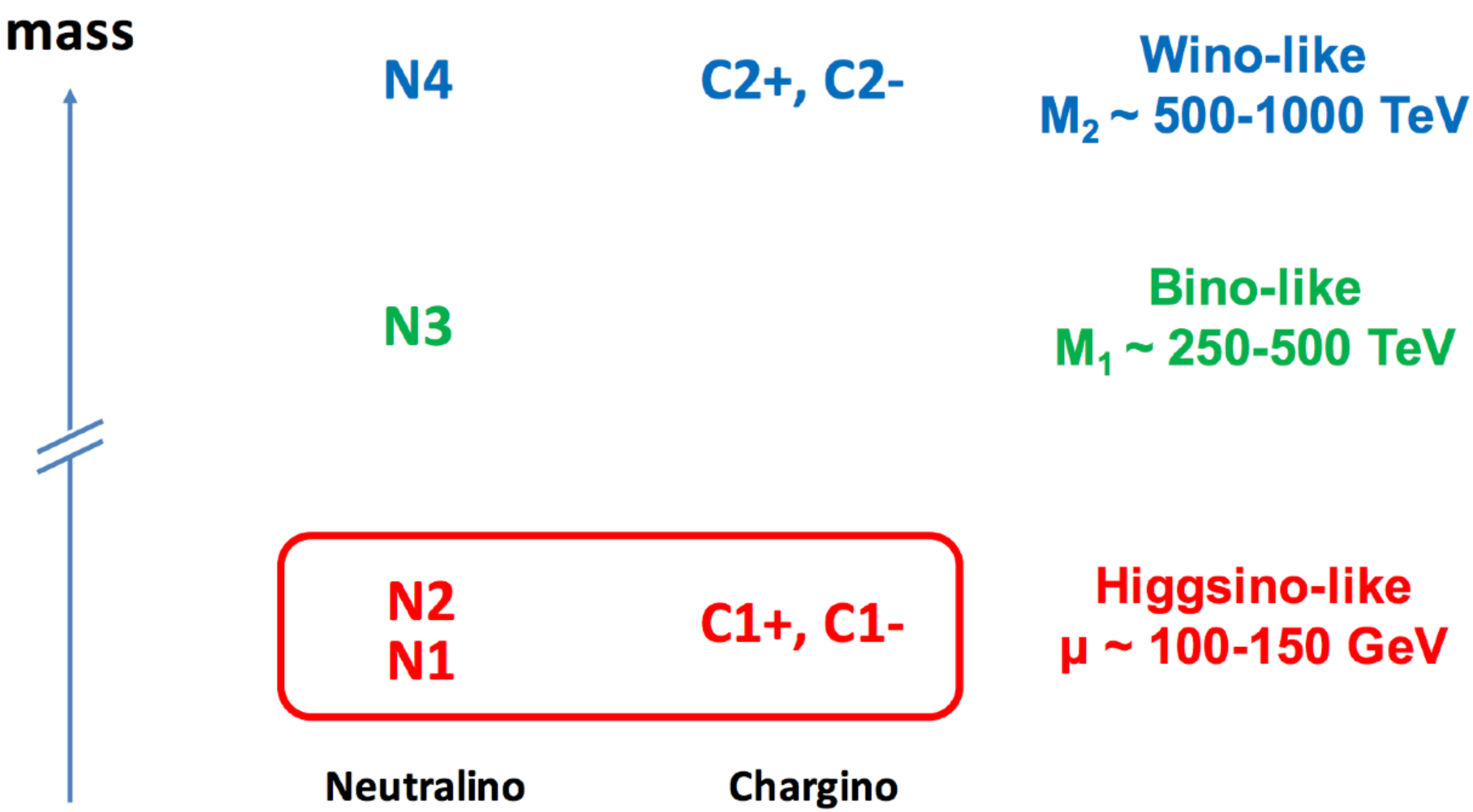
dM1600

Reconstruction efficiency for $\gamma\gamma \rightarrow$ low pt hadron tracks

- ILDPerformance -Diagnostics package used for tracking efficiency
- Silicon Tracking algorithm used to reconstruct tracks
- Reconstruction efficiency of $\gamma\gamma \rightarrow$ low p_T hadron events consistent with $t\bar{t}$ events
- Reconstruction efficiency for the low pt hadron events
  - Above 300 MeV and at higher angles 99%
- Important to develop method to remove $\gamma\gamma \rightarrow$ low pt hadron events



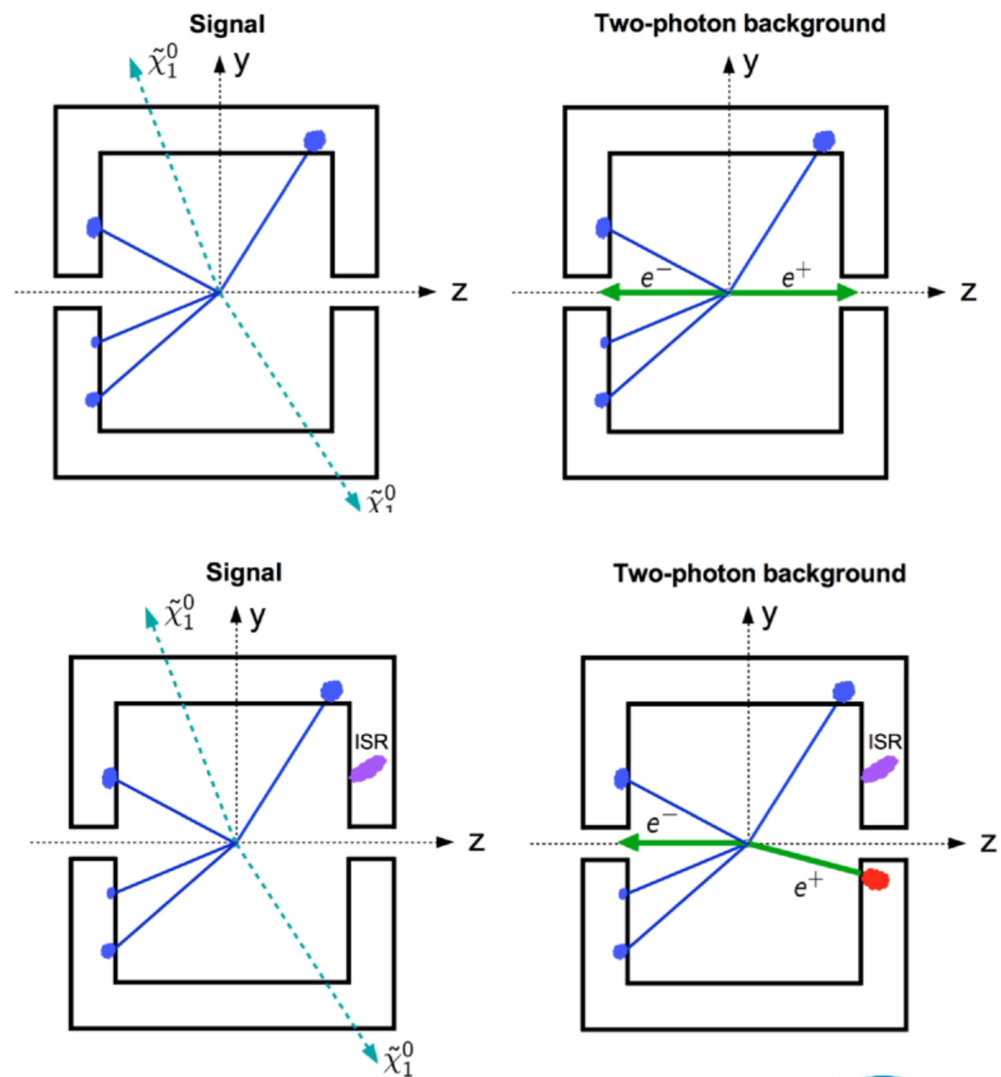




ref. Tomohiko Tanabe

Precuts for the Algorithm

- The event should have a hard ISR photon with E > 10 GeV
- ISR photon gives a pt kick to the beam electron - beam electron within detector acceptance
- Missing energy from beam particles - overlay events
- For signals - the pt kick balanced by the invisible neutralinos
- No effect on the signal decay products or the beam electron

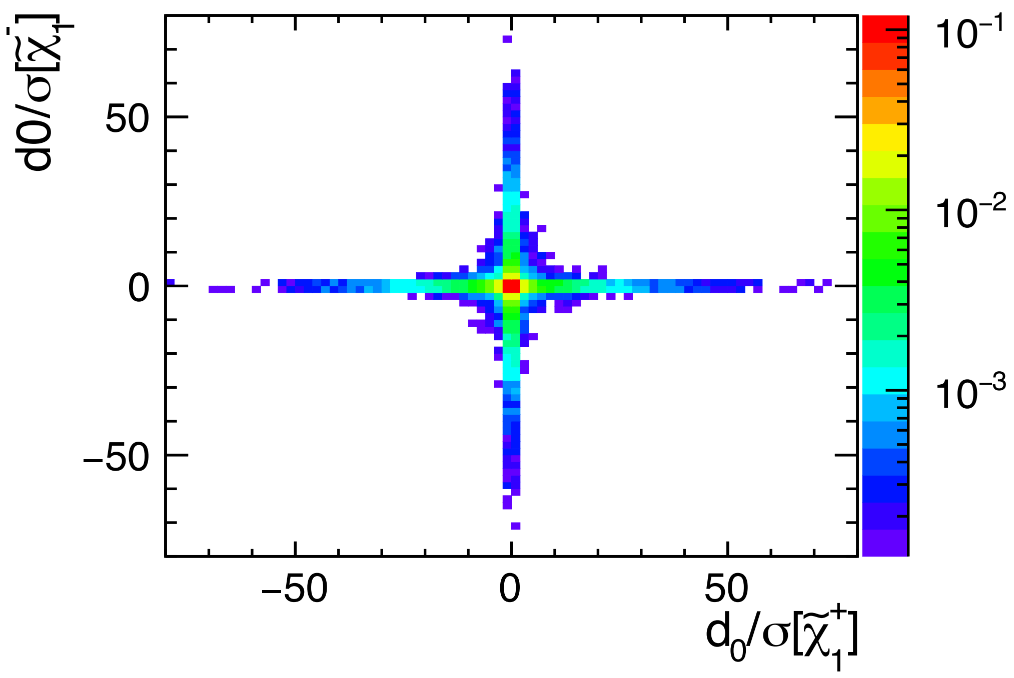


Summary and Outlook

- Although physics environment at ILC is very clean $\gamma\gamma$ backgrounds is still important
- The impact of this overlay is found on a very few specific but important events
- A better generator to produce $\gamma\gamma \to$ low pt hadrons was developed with more realistic particle contents for events
- Investigating whether different z_vtx position and vector meson tag can be used to remove the backgrounds
- Work in progress!!
- OUTLOOK:
  - The method developed will be applied on higgsino samples and Hale Sert's study would be repeated but with inclusion of $\gamma\gamma$ overlay

Detailed study of d_0 parameter

- Chargino - different branching ratios but always decays into one charged particle
- Every event should have two tracks from the signal ($\tilde{\chi}_1^+, \tilde{\chi}_1^-$)
- The d_0 significance of the two tracks of the signal are plotted
- 60 % cases one track has high value of d0 significance and other is smaller
- Rest 40 % cases d_0 significance for both tracks are similar



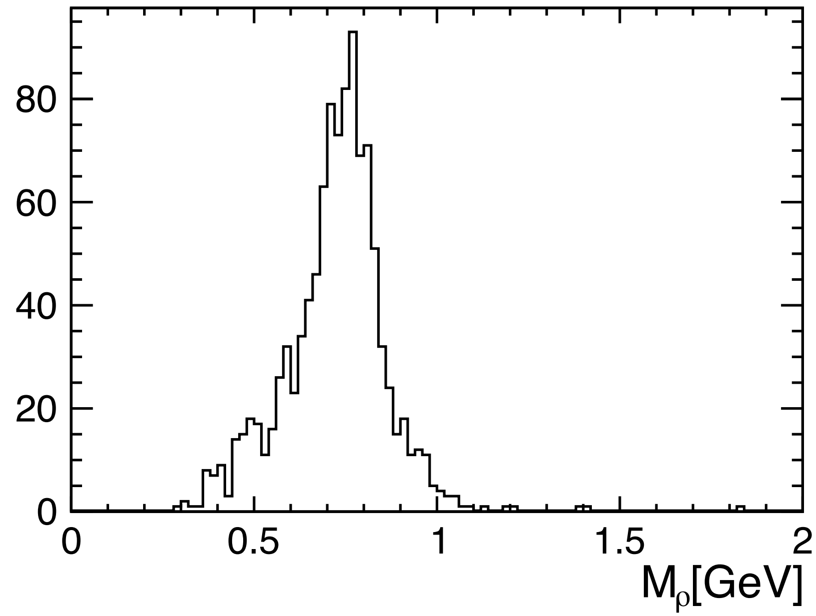
Method Development to remove backgrounds

- Primary step - separating events as in table
  - Pythia events complex - 55 % events - good chances for finding vertex
  - Only Separating Barklow events as below - 45 %

Processes	No. events [%]	Methods to tackle
$\gamma\gamma \rightarrow \pi^+\pi^-$	33.43 %	displaced vertices
$\gamma\gamma \rightarrow \pi^0\pi^0$	5.68 %	only photons 🙁
$\gamma\gamma \rightarrow \rho^+\rho^-$	1.26 %	displaced vertices & rho tag
$\gamma\gamma \rightarrow \rho^0\rho^0$	2.68 %	displaced vertices & rho tag
$\gamma\gamma \rightarrow \rho^0\omega$	0.7 %	displaced vertices & rho tag

Method - Using Rho meson tag

- $\gamma\gamma \rightarrow \rho^0\rho^0$ events - rho meson decay to two π^+ and two π^- (2.68 %)
  - Events with exactly 2 $^{+ve}$ and 2 $^{-ve}$ tracks selected
  - Invariant mass calculated from two different combinations
  - mass closest to rho meson chosen and plotted
  - The pion combinations give rho mass - 770 ± 145 MeV
  - Only 0.54% events reconstructed exactly as 2 $^{+ve}$ and 2 $^{-ve}$ tracks



Event Properties of Pythia

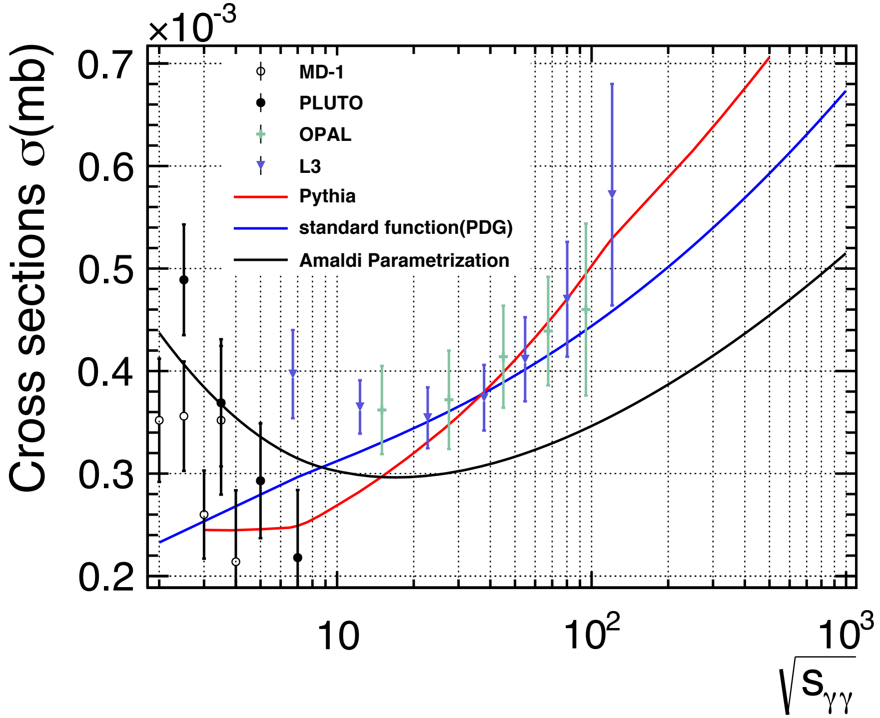
- Direct Interactions(DIR) - Real photons interacts directly
- Vector Meson Dominance(VMD) - Photon fluctuates into a vector meson
- Anomalous Interactions(GVMD) - Photon fluctuates into a $q\bar{q}$ pair of larger virtuality
- Deep inelastic Scattering(DIS) - A process of probing the Hadrons with very high energy leptons.

Subprocesses	Cross-sections (nb)
VMD * VMD	239.2
DIR * VMD	87.52
GVMD * DIR	9.77
GVMD * GVMD	12.05

> Pythia cannot simulate below 2 GeV

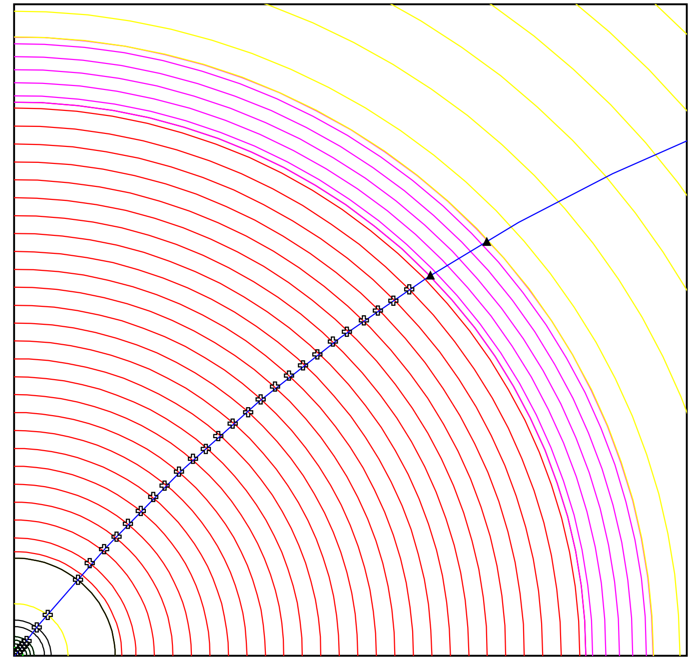
Cross sections for Pythia events

- Comparison of $\gamma\gamma \to$ low Pt hadron process cross sections from Pythia with PDG, Amaldi et.al(hep-ph/9305247) and data from LEP,PETRA and VEPP
- $\sqrt{s_{\gamma\gamma}} > 10$ GeV : Good description of LEP data with Pythia
- $\sqrt{s_{\gamma\gamma}} < 10$ GeV: Measurements have large uncertainties and widespread
- Pythia event properties studied in detail for better understanding



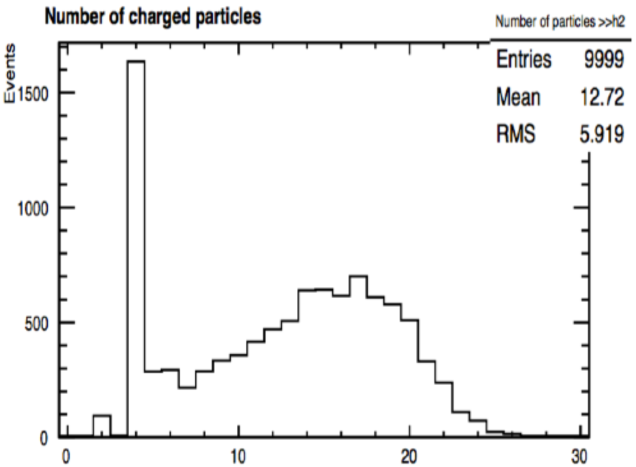
Does $\sqrt{s_{\gamma\gamma}}$ < 1 GeV matter?

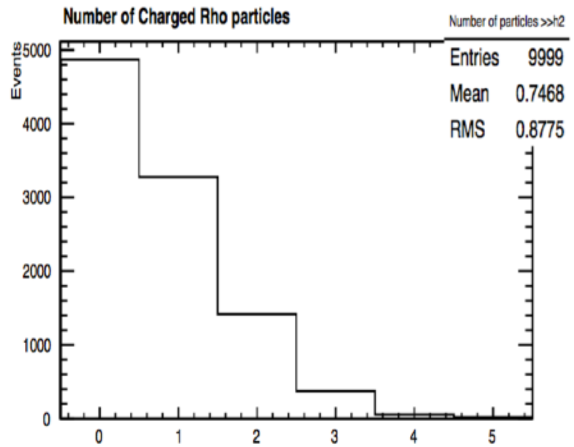
- Detector acceptance for $\sqrt{s_{\gamma\gamma}} < 1$ GeV
  - Select events $\sqrt{s_{\gamma\gamma}} < 1$ GeV
  - Events generated from real-real, real-virtual and virtual-virtual photon collisions
  - Simulate ILD in SGV fast simulation
- Reconstruction in SGV
  - Particles having ≥ 3 layer hits : "Charged"
  - Particles hitting calorimeter : "Neutral"

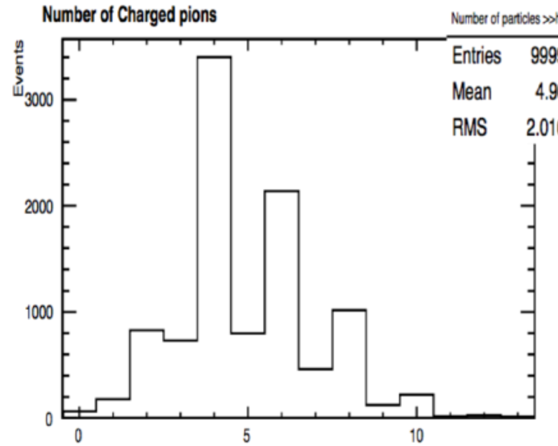


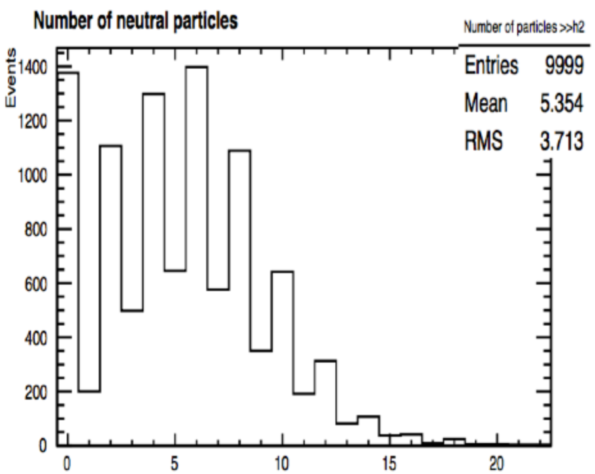
Ref: archiv:1203.0217v1

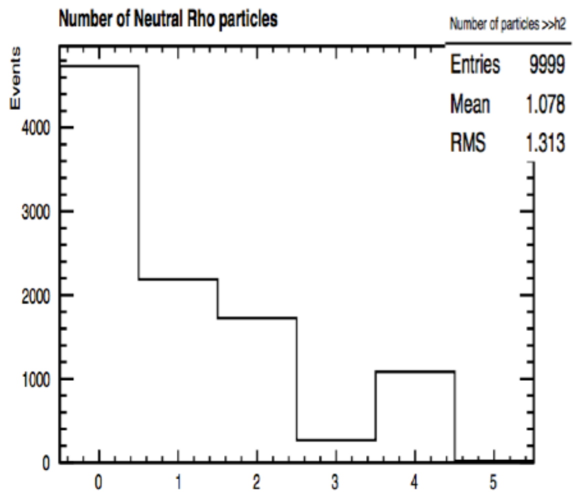
Event Properties of Pythia

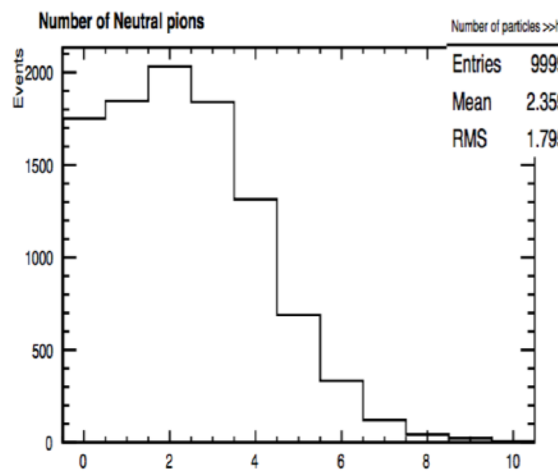






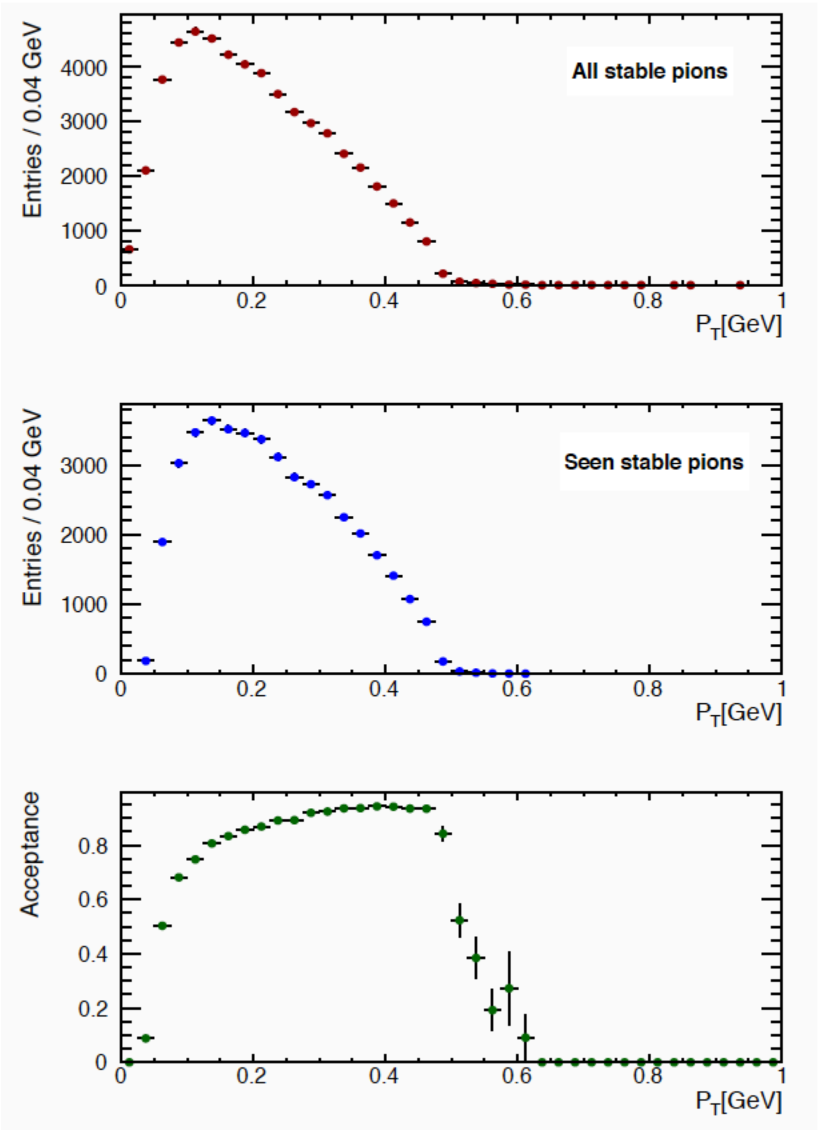




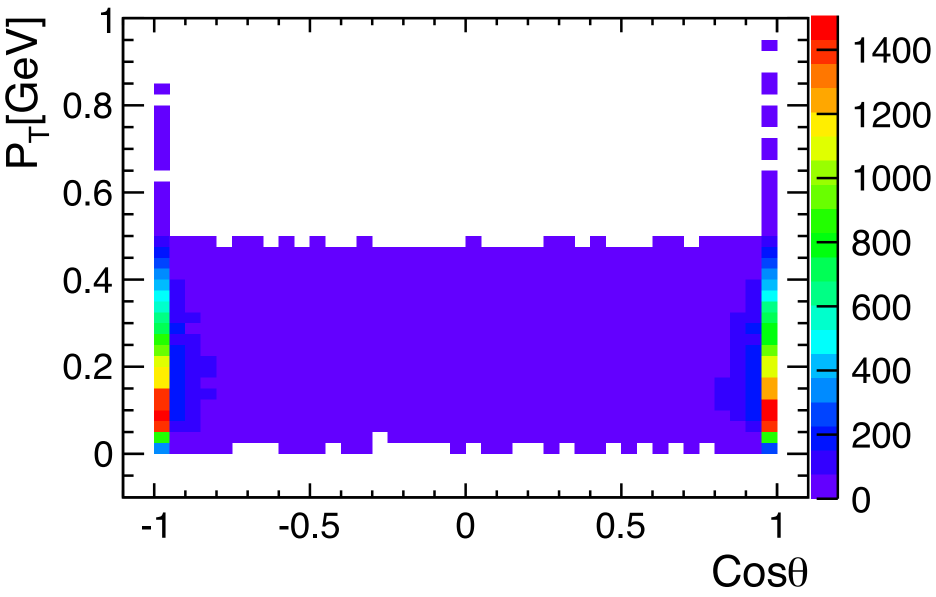


Pythia could be used to simulate events down upto $\sqrt{s_{\gamma\gamma}} = 2$ GeV

Momentum acceptance for Pions

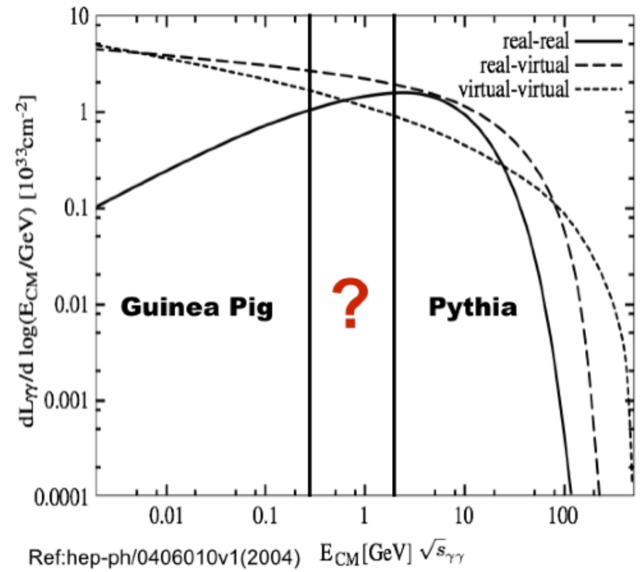


- Momentum acceptance:
  - Dividing seen stable pions with all true pions
  - The acceptance for most particles > 80%
  - Particles with high Pt but moving in forward direction - low acceptance



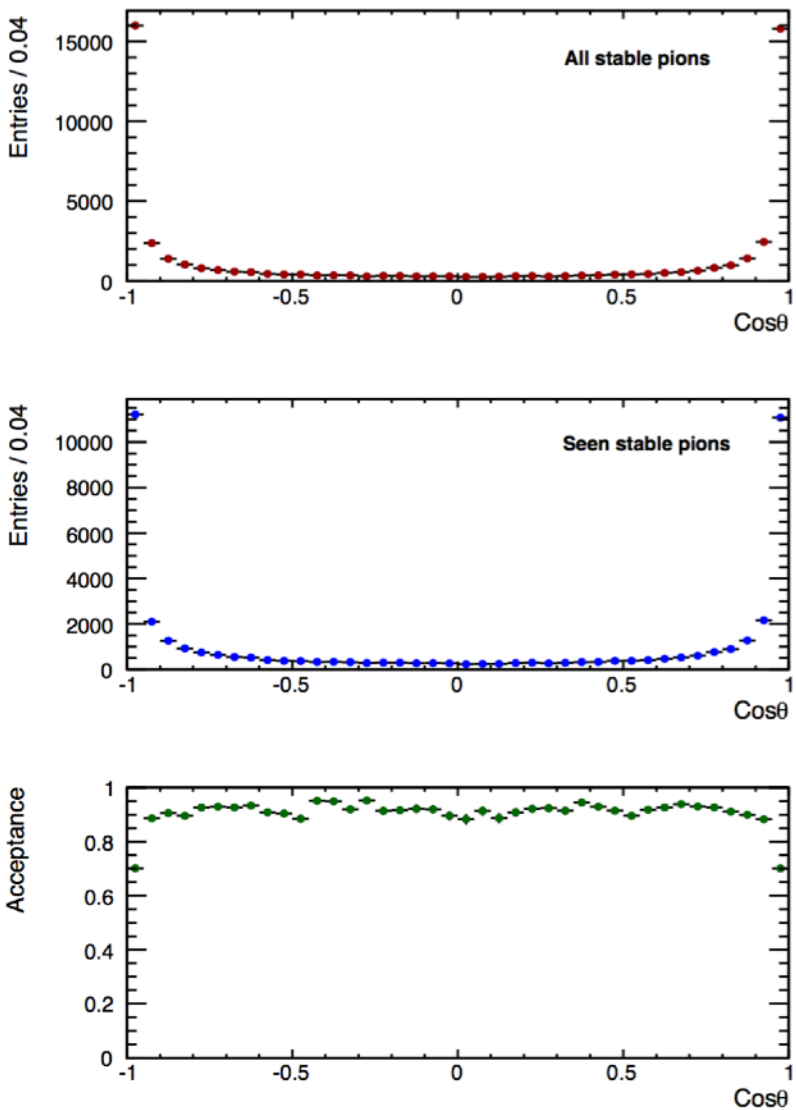
A dedicated event generator for $\gamma\gamma$ processes

- For $\sqrt{s_{\gamma\gamma}} > 2$ GeV Pythia 6 used to simulate $\gamma\gamma \rightarrow$ low pT hadron processes
- Below $2\ \pi_m$ pure QED beam-beam interactions modeled by dedicated programs - Guinea Pig
- Need to evaluate the impact of uncovered region - how can it be modeled?
- Dedicated generator developed in ILC community to study low energy region by Tim Barklow
- The particles below 2 GeV - Very low Pt
- Could these particles be observed in the detector?
- How important is it to model this area?

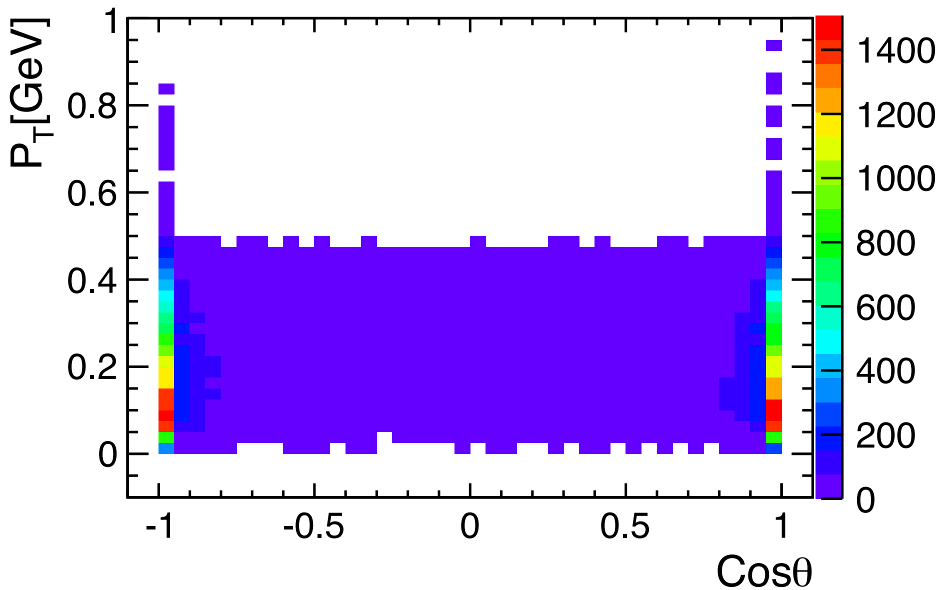


Ref:hep-ph/0406010v1(2004)

Angular acceptance for Pions

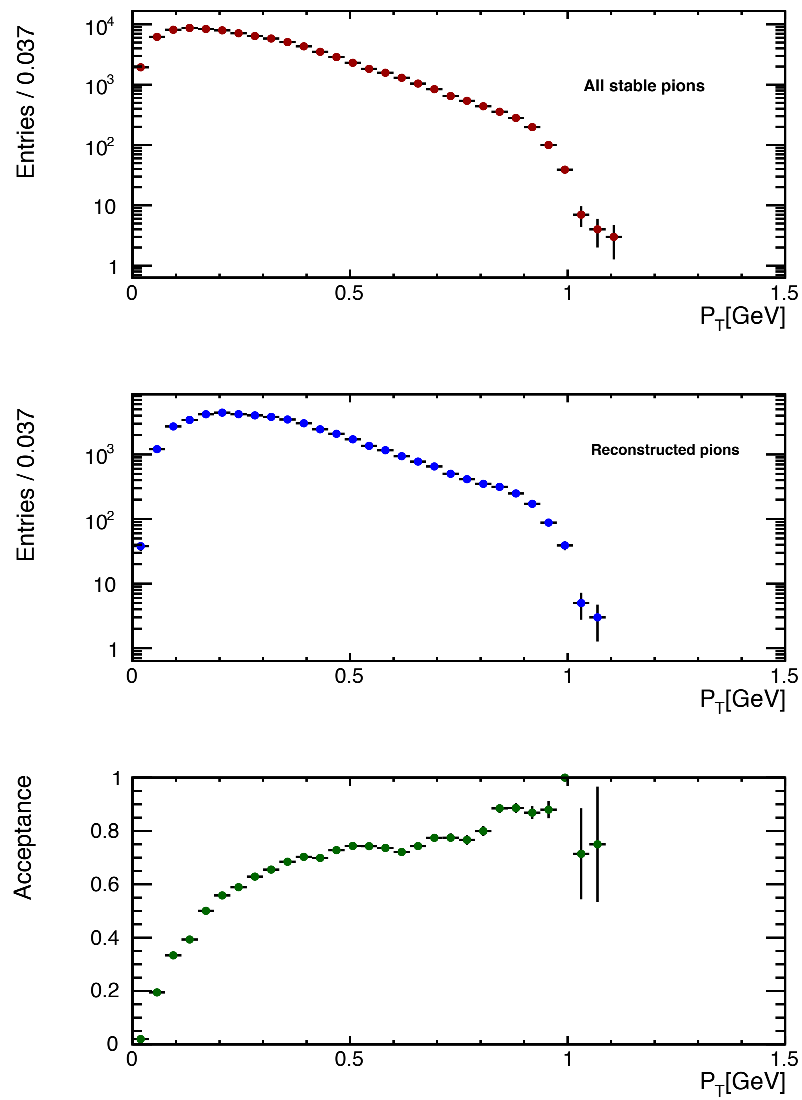


- Angular acceptance:
  - Dividing seen stable pions with all true pions
  - The acceptance for most particles > 80%
  - Particles with high Pt but moving in forward direction - low acceptance



Momentum acceptance of pions with full simulation

- Cross checked the results with full simulation
- acceptance for pions at $\sqrt{s_{\gamma\gamma}}$ 2 GeV
- Acceptance reasonable enough to model the region below 2 GeV
- Work under progress to confirm the results



Modeling the low energy regime

- The issues discovered studied and conveyed to the author
- As expected from Chiral sum rule and Regge theory the generator now produces large variety of events
- The cross-sections for producing ρ^0 is greater than $\rho^{\pm}$
- A better version of the generator was thus developed correcting the issues in older version- big progress!!!